Nationale Genossenschaft für die Lagerung radioaktiver Abfälle
Société coopérative nationale pour l'entreposage de déchets radioactifs
Società cooperativa nazionale per l'immagazzinamento di scorie radioattive

NAGRA

TECHNISCHER BERICHT 80-04

FEASIBILITY STUDY FOR LARGE DIAMETER BOREHOLES FOR THE DEEP DRILLING CONCEPT OF A HIGH-LEVEL WASTE REPOSITORY

OCTOBER 1980

SERVICES TECHNIQUES FOREX NEPTUNE S.A., PARIS

Geschäftsstelle Parkstrasse 23 CH–5401 Baden Telephon 056/22 01 82

Nationale Genossenschaft
für die Lagerung
radioaktiver Abfälle

Société coopérative nationale
pour l'entreposage
de déchets radioactifs

Società cooperativa nazionale
per l'immagazzinamento di
scorie radioattive

NAGRA

TECHNISCHER BERICHT 80-04

FEASIBILITY STUDY FOR LARGE DIAMETER BOREHOLES FOR THE DEEP DRILLING CONCEPT OF A HIGH-LEVEL WASTE REPOSITORY

OCTOBER 1980

SERVICES TECHNIQUES FOREX NEPTUNE S.A., PARIS

Geschäftsstelle Parkstrasse 23 CH–5401 Baden Telephon 056/22 01 82

P R E F A C E

This is a summary of a study made by FOREX NEPTUNE within the scope of a consultancy contract with Nagra.

The mentioned study aims at evaluation and demonstration of the feasibility of sinking large diameter boreholes for the storage of nuclear waste using existing drilling technology.

The work was carried out by Jean-Pierre DORBATH as project engineer, with contributions from:

- André REY-GRANGE, Manager of Research and Engineering Department
- Serge CORDIER, Assistant Operation Manager
- Bernard MAURICE, Operation Engineer

and using the experience of FOREX-NEPTUNE in oil weel and big hole drilling practices.

This present report largely reproduces the internal report submitted by Forex Neptune, in order to make it available to a broader public. Some chapters have been summarized. Final editing was performed by Nagra.

S U M M A R Y

INTRODUCTION (Chapter 1)

The combustion of nuclear fuels generates radioactive wastes, some of which are very long lived and must be kept in confinement for very long periods, up to 100 000 years. One proposed method of confinement is to bury the wastes containers in stable formations at depths of a few thousand metres, by means of holes drilled with existing oilwell equipment and techniques. This study endeavours to evaluate whether drilling these holes is possible with presently available technology.

DESCRIPTION OF THE CONCEPT (Chapter 2)

The formation choosen for the repository is granite, and the geological profile selected, for a well depth of 2'000 m is:

0 to 1'000 m:	sedimentary, overlaying
1'000 to 2'000 m:	granite, massive.

Additional requirements calling for a minimum separation between two storage zones, and for a minimum impact on the environment of both the drilling and subsequent operations, lead to a concept where a certain number of deviated and orientated holes are drilled from a single location. One storage arrangement proposed has 9 wells, in line at the surface with a 6 m spacing, and diverging as the depth increases, with a minimum angle to the vertical of 7^{o}. By increasing the maximum allowable angle of a hole to 15^{o}, one can design a storage arrangement with 19 wells drilled from the same rig location.

The characteristics of the geological formation govern the chemical and physical characteristics of the fluid used to drill a well, and also the architecture of such a well (particularly the depths at which intermediate technical casings must be used). Pending confirmation of the characteristics of the various overlaying formations (such confirmation will be given by exploratory holes, in which a number of parameters will be measured), the proposed architecture is:

- 56" OD. conductor pipe set at 50 m
- 36" OD. technical casing set at 800 m, in a 48" diameter hole
- 22" OD. final casing set at 2'000 m in a 30" diameter hole.

One important function of the drilling fluid is to evacuate the rock cuttings from the hole. This can be performed only if the fluid has a minimum ascending speed. With existing pumps, and "normal" circulation (fluid going down inside the drilling string and up in the annulus between bore hole walls and drilling string), the maximum achievable diameter is 26" to 30". The drilling technique and sequence of operations will therefore be:

- Setting 56" conductor pipe at 50 m.
- Drilling 26" hole to 800 m, deviating and orientating such hole as per program.
- Opening 26" hole to a diameter of 48", with air assisted reverse circulation technique.
- Run and cement 36" casing.
- Drill 30" hole to total depth, maintaining as much as possible the previous deviations and direction.
- Run and cement 22" casing.

The exploratory wells will supply most of the information needed to adjust such a program and to estimate a realistic deviation for one well. One can assume that drilling such a hole will take 10 to 12 months.

TECHNOLOGICAL COMPONENTS (Chapter 3)

Conductor pipe

This can be selected from the available A.P.I. standardized line pipes, with a thickness of 1". Considering the short length of pipe to be set, the different sections will be welded together, and the pipe can be either driven with heavy hammers or cemented conventionally into a predrilled hole.

Casing strings

Both 36" and 22" casing strings have larger diameters than the standard oilwell casings, and must therefore be specially manufactured. Adopting design factors which are commonly used for oil wells, it is possible to select such a steel quality (K.55) and pipe thickness (1"), that any specialized steel plant will be able to manufacture these pipes without particular difficulty. Manufacturers of connectors can also extend the range of commercially available joints to the needed diamter of 36" and 22".

Cementing

The casing strings must be (at least partially) cemented to ensure separation between formations and to assist in supporting the weight of the casing. Conventional Portland cement, with different additives can be used for this purpose. Due to the very large volumes of slurry to be displaced and to the potential losses of slurry into weak limestones, the cementing operation will justify a careful preparation and planing and may require remedial actions, such as additional cementing into the annulus.

Piloting a well

Drilling a deviated and orientated well in order to reach a target at a certain depth is a very common operation in development drilling. The measuring equipment is available and the deviation control (or trajectory corrective) techniques are fully reliable. The storage arrangement as proposed allows some departure from the theoretical curves without jeopardizing a previously drilled well.

Drilling fluids

Mud is likely to be the most used fluid for the safe drilling of the holes. Due to the existence of a massive salt layer, it will not be possible to use the same mud for the whole well, and if mud treating section and pumping equipment are conventional, the storage of large volumes of drilling mud, some of it corrosive, will require original solutions.

Drilling equipment

The most powerful drilling machinery (pumping and lifting equipment particularly) available today is sufficient to drill and case the contemplated wells, and the down hole tools (drill pipes, drill collars and drilling bits), can be selected within the range of standard equipment.

Well Heads - Blow out Preventers

Well heads will have to be completely designed and developed for these unusual sizes, but they can be manufactured without any difficulty from welded steel plates. Blow out prevention will rely mostly on the knowledge of the formations and on specially made large diameter preventers, preferably ram type.

IMPACT ON THE ENVIRONMENT (Chapter 4)

Pollution and emissions can be kept to a minimum by specific design of the drilling machinery and of the area of recovery of cuttings, mud spills, etc. . In addition one must bear in mind that the drilling site will be used for a number of years, so that it is well worth designing and arranging it with particular care.

CONCLUSION

It is possible today to drill and case holes with such a diameter and at such depth as required for the fulfilment of the various requirements laid down in the "Deep Drilling Concept".

In addition, it is possible to design a particular architecture for individual holes, which will allow the drilling of a large number of wells from a single location, thereby reducing as much as possible the impact of drilling operations on the environment.

TABLE OF CONTENTS

		Page
	PREFACE	I
	SUMMARY	II
	TABLE OF CONTENTS	VI
	LIST OF DRAWINGS	IX
	LIST OF ABREVIATIONS	X
	LIST OF UNITS	XI
1.	INTRODUCTION	1
1.1	Storage of nuclear fuel wastes	1
1.2	Particulars of the drilling industry	1
1.3	Some drilling achievements	3
2.	DESCRIPTION OF THE CONCEPT	4
2.1	Geological profile - Choice of storage depths	4
2.1.1	Depository formation	4
2.1.2	Geological profile - Storage depth	4
2.2	Basic data or requirements	5
2.2.1	Hole size	5
2.2.2	Verticality	5
2.2.3	Separation of storage holes	5
2.2.4	Environment and pollution	5
2.2.5	Depth of storage	5
2.3	Selection of a well path and storage architecture	6
2.3.1	Uncontrolled drilling	6
2.3.2	Comments on deviation control	6
2.3.3	Selection of a well path	7
2.3.4	Storage arrangement	8
2.3.5	Alternative storage arrangement	8
2.4	Architecture of the well	9
2.5	Drilling technique - Sequence of operations - Planning	11

TABLE OF CONTENTS

		Page
3.	TECHNOLOGICAL COMPONENTS	13
3.1	Surface conductor-pipe	13
3.1.1	Purpose	13
3.1.2	Pipe and connections	13
3.1.3	Conductor-pipe setting technique	14
3.2	Casing strings	15
3.2.1	Steel quality	15
3.2.2	36" casing string - pipe body	16
3.2.3	22" casing string - pipe body	16
3.2.4	Couplings	16
3.2.5	Casing strings - accessories	17
3.2.6	Casing handling	17
3.3	Cementing	18
3.3.1	The cement	18
3.3.2	Slurry and cement volumes	18
3.3.3	Surface equipment	19
3.3.4	Quality control	21
3.3.5	Conclusion	21
3.4	Monitoring and piloting a well	22
3.4.1	Measuring equipment	22
3.4.2	Measuring techniques	23
3.4.3	Piloting a well	23
3.4.4	Comments	24
3.5	Drilling fluids	25
3.5.1	Mud properties	25
3.5.2	Mud treating equipment	26
3.5.3	Pumping equipment	27
3.5.4	Mud storage	27
3.5.5	Mud products storage	28
3.5.6	Conclusion	28
3.6	Drilling equipment	29
3.6.1	Pumping equipment	29
3.6.2	Lifting equipment	29
3.6.3	Drill pipes	29
3.6.4	Drill collars	30
3.6.5	Drill bits and hole openers	30
3.6.6	Conclusion	31
3.7	Well heads - Blow-out preventers	32
3.7.1	Well heads	32
3.7.2	Blow-out preventers	33
3.8	Electrical logging	35

TABLE OF CONTENTS

		Page
4.	IMPACT ON THE ENVIRONMENT	36
4.1	Pollution - Nuisances	36
4.1.1	The mud	36
4.1.2	The cuttings	36
4.1.3	The noise	37
4.2	Occupation of space - Drill site arrangement	37
4.2.1	Site preparation	37
4.2.2	Access roads to the site	37
5.	DEPTH LIMITS	39
5.1	Cased hole	39
5.2	Uncased hole	39
5.3	Conclusion	40

LIST OF DRAWINGS

Fig. 1: Example of deviated wells

Fig. 2: Suggested well path

Fig. 3: Storage arrangement

Fig. 4: Alternate: High capacity storage

Fig. 5: Alternate wells paths

Fig. 6: Architecture of a well

Fig. 7: Reverse circulation - Principle

Fig. 8: Planning

Fig. 9: Locking dog connectors

Fig. 10: Special connectors

Fig. 11: Casing cementing

Fig. 12: Mud storage

Fig. 13: Well heads

Fig. 14: Cellar arrangement

Fig. 15: Driling site - General arrangement

Fig. 16: Alternate hole architecture

LIST OF ABREVIATIONS

A.P.I. : American Petroleum Institute

B.H.A. : Bottom Hole Assembly

B.O.P. : Blow-Out Preventer

B.U.R. : Build Up Rate

C.S.G. : Casing

D.O.R. : Drop Off Rate

D.P. : Drill Pipe

I.D. : Inside Diameter

K.O.P. : Kick Off Point

M.D. : Measured Depth

O.D. : Outside Diameter

T.M.D. : Total Measured Depth

T.V.D. : Total Vertical Depth

V.D. : Vertical Depth

LIST OF UNITS

Centimeter (cm):	1/100 of a meter
Gallon:	U.S. Gallon $\sim$ 3,78 liters
Inch (in or"):	2,54 cm
Kilogram force (kgf):	$\sim$ 9,81 Newton
Pound (lb):	0,453 kg
Pound per square inch (psi):	$\sim$ 0,070307 kg/cm^2
Megawatt (MWe):	10^6 Watt

1. INTRODUCTION

1.1 Storage of nuclear fuel wastes

In reprocessing plants the spent nuclear fuel is separated into re-usable fissionable materials and waste products.

The high level waste is fixed into a glassmatrix which has to be isolated from the biosphere for many tens of thousands of years.

One of the methods which may be satisfactory for the safe disposal of these wastes is:

- Storage of the containers in deep holes, drilled with an adapted hole drilling technique, and reaching the geologically stable basement (crystalline bedrock) to be used as depositary formation.

The purpose of this feasibility study is to evaluate the possibility of drilling such holes, using today's proven equipment and technology. Even though new tools, equipment or techniques are likely to be developed in the near future, we have based our concept and comments on what is available, or can be made today.

Before developing our concept and its various components, we think it is advisable to mention a few characteristics of the drilling industry.

1.2 Particulars of the drilling industry

1.2.1 Although drilling is an old technology (holes were drilled in the ground by the Chinese 2'000 years ago), the modern drilling industry is extremely dynamic and competitive, and has the ability to design and develop quickly new generations of equipments, tools or techniques whenever the need arises. This is demonstrated, for example, by the pace of development of offshore operations.

1.2.2 It is a very diversified industry, making use of a large variety of sciences and technologies (geophysics, geology, chemistry, metallurgy, electronics, to name but a few), and the expertise and know-how are spread amongst a large number of companies, each highly specialized in a narrow field. It is not therefore surprising that drilling a well should usually require the assistance and cooperation of such service companies as:

1.2.2.1 Drilling contractor: supplies the drilling rig and the personnel to operate it.

1.2.2.2 Mud service contractor: engineers the mud program, supplies the mud chemicals and additives, supervises mud preparation and maintenance on the drilling site.

1.2.2.3 Cementing contractor: engineers the cementing program, supplies the cement, storage bulks, cement pumping equipment and service.

1.2.2.4 Deviation contractor: responsible for maintaining deviated wells on their theoretical trajectory.

1.2.2.5 Geological service: collects samples of the formations, analyses and identifies them, delivers the geological log of the well.

1.2.2.6 Electric logging contractor: performs the electrical logging in the well, interprets the logs.

1.2.2.7 As needed, a large variety of other specialists such as tubular inspection service, production or completion equipment manufacturers, well testing service, well control specialists etc.

1.2.3 In spite of its world-wide expansion, the drilling industry is dominated by the U.S.A. Most modern drilling techniques and tools were developed in the U.S.A.; 95 % of all drilling rigs operating outside the Iron Curtain were, and are completely built in the U.S.A. The approx. number of land rigs operating today is:

- U.S.A.	2'900
- CANADA	300
- Rest of the world (outside Iron Curtain)	1'100
TOTAL	4'300

The background of the drilling industry and the present weight of the U.S. manufacturers and contractors explain, for example, why the measuring units used are generally the U.S. units (inch, foot, gallon etc.), and why the universally accepted standards are those issued by the American Petroleum Institute (A.P.I.). With the exception of depth measurements (meters) americain units are therefore used in this study .

1.3 Some drilling achievements

Among the most prominent performances of the past few years, one can mention:

- Drilling of a 3 m diameter hole down to a depth of 1'500 m, for the A.E.C. in the Nevada Desert, U.S.A. This hole was not cased.

- Drilling several wells below 9'000 m, in Anadarko Basin, Oklahoma, U.S.A. The holes were cased to bottom.

- The deepest casing strings are:

  - 20" : 2'050 m
  - 13 5/8" : 4'700 m (weight in mud: 635 tonnes)

Those feats, requiring a very careful planning and follow-up of all operations, were performed with what is basically "off the shelf" equipment. They have been widely advertized and described in the specialized literature, and even if full details on all the aspects of these performances are not always disclosed, the experience acquired by the various manufacturers and service companies benefits this study.

2. DESCRIPTION OF THE CONCEPT

2.1 Geological profile - Choice of storage depth

2.1.1 Depository formation

The formation selected for storage of high active wastes, in order to maintain its confinement during the contemplated period, must have the following characteristics:

- It must be geologically stable, thick, massive and have low permeability.
- It would be advantageous if covered by other sedimentary formations, themselves thick enough to protect efficiently the depository formation in any foreseeable event.

Among the various formations having these properties, granite seems to be a good choice, its thickness allowing large capacity storage wells (i.e. reducing the number of wells to be drilled).

2.1.2 Geological profile - Storage depth

The geological profile selected for the feasibility study is (Ref. Nagra, Appel d'Offre, 15 Mai 1979, Annexe 1):

0 to - 50 m :	sand, gravel
50 to - 200 m :	limestone
200 to - 400 m :	marl
400 to - 500 m :	limestone
500 to - 600 m :	marl
600 to - 700 m :	claystone
700 to - 800 m :	marl and anhydrite interbeddet
800 to - 880 m :	salt
880 to - 1000 m :	marl and anhydrite interbedded
1000 to - 2000 m :	granite

The holes would therefore be 2'000 m deep, the bottom 500 m (i.e. - 1'500 to - 2'000 m) used as storage, the upper 500 m of granite and the 1 000 m of sedimentary formations being additional barriers.

2.2 Basic data or requirements

2.2.1 Hole size

The diameter of the hole has been specified as 20", inside diameter of the final casing string at bottom.

2.2.2 Verticality

It does not appear that the hole must be strictly vertical, as long as the containers, and any other tools used for the storage and sealing operations can be run or retrieved freely.

2.2.3 Separation of storage holes

For various reasons (one being the dissipation of the heat generated by the containers in storage), a minimum distance must be maintained between two adjacent storage wells. This minimum distance has not yet been accurately calculated but a first estimate is 30 meters.

2.2.4 Environment and pollution

The impact of the drilling operation on the environment should be kept as low as possible. For example, land being at a premium, the wells should preferably be drilled in groups, close to one another, from a single location, rather than scattered over a large area. Having a number of wells at the same location will also make future use and protection (during the handling period) of the storage area much easier by concentrating temporary storage buildings, handling equipment etc. This cannot, however, be achieved at the cost of a reduction of the separation requirement.

2.2.5 Depth of storage

The study is limited to the 2'000 m cased hole. However, maximum depth achievable with the same parameters has been determined, and an alternative architecture for the well, without casing for the storage zone, is proposed in chapter 5.

2.3 Selection of a well path and storage architecture

2.3.1 Uncontrolled drilling

- Exploration oilwells are usually drilled without any particular concern for the actual deviation (which often reaches values of 10^{o} to 15^{o}) as long as it does not hamper drilling operations. The only concern relates to abrupt changes of the deviation or direction of the hole ("dog legs"), likely to be a source of problems during trips in or out of the hole. These dog legs are avoided by using very stiff bottom hole assemblies, i.e. large drill collars and stabilizers.

- However, when drilling two such wells in homogeneous formations and close to one another, small unavoidable variations in the drilling parameters or drilling bit action will result in the two holes not being absolutely parallel.

- If one wants to guarantee a minimum 30 m separation between two wells, one is obliged to spud the wells in at a much larger distance, which could be as much as 80 or 100 m for the 2'000 m deep wells. Drilling any number of wells from the same location would then result in the need for a very large land area.

- Our concept has therefore been orientated towards the drilling of deviated directional wells, close to one another at the surface and diverging as the depth increases.

2.3.2 Comments on deviation control

2.3.2.1 Deviation of a well can naturally be measured only after it (or a section of it) has been drilled, and the path curve is derived from a number of measurements (taken for example every 100 m).

2.3.2.2 Maintaining a well as close as possible to a predetermined path is therefore generally quite difficult and may require a great number of trajectory corrections, increasing drastically the cost of the well.

The concept of the storage should be such that it allows some leeway around theoretical curves of the wells, in order to reduce the need to follow them very accurately.

2.3.2.3 Whenever the choice is possible, "soft" formations are choosen to initiate the deviation of the well ("kick-off").

2.3.2.4 All the equipment and know-how available within the industry for deviation control relate to "small" holes, 7" to 15" range.

However, successful trials have been made recently in deviating and orientating holes of 26" diameter.

2.3.2.5 It is our experience that large diameter holes have a tendency to follow a straighter path than conventional oilwells.

2.3.3 Selection of a well path

2.3.3.1 Shape of the well

Deviated wells can have quite a variety of shapes, but the most common are (fig. 1):

- Slant shape, curve 1
- "S" shape, curve 2

It can be seen that, to reach the same point, "S" shaped well will have two curved zones (build-up and drop off) against only one for the slant shape, and that its maximum angle will be significantly higher ($19^{o}22'$ versus $11^{o}07'$ in our example).

If we admit that the storage zone (i.e. the bottom 500 m of the well) does not have to be vertical, it is better to select a slant shaped well.

2.3.3.2 Selected well path

In order to make actual control of deviation and direction (azimuth) of a well possible, the deviation itself must be higher than 5^{o}. We therefore select a well path as shown on fig. 2, featuring a very gentle build-up rate of $1^{o}/30$ m, and a maximum angle of $7^{o}05'$.

The separation with the vertical line from surface varies between 135 m at top of the storage zone and 200 m at its bottom (depth 2'000 m).

The additional length of hole to be drilled due to its deviation is only 12 meters.

2.3.4 Storage arrangement

2.3.4.1 On offshore platforms, wells are usually drilled in "clusters", or in grids, with for example 4 rows of 6 wells each. However, on land, it is certainly simpler to drill them "in line". The transfer of the drilling machinery from one well to another can then be performed without any dismantling, by simple skidding devices.

2.3.4.2 The spacing between adjacent wells is very often reduced to 2,40 m or even 1,80 m on offshore platforms. We think that it is safer to adopt the figure of 6 m. It will not greatly increase the necessary land area, but will drastically decrease the possibility of 2 wells interferring in their straight vertical section.

2.3.4.3 We selected , therefore, a storage arrangement as shown on fig. 3. This pattern of holes shows a theoretical minimum distance between two storage zones of 120 m, well above the given figure of 30 m. This can be considered as a safety margin, allowing some relaxations on the deviation control requirements: a well may depart slightly from its theoretical trajectory, without jeopardizing previously drilled wells by coming too close to them.

2.3.5 Alternative storage arrangement

2.3.5.1 One can increase the number of wells drilled from one location by reducing the angle of 45^o between two wells (fig. 3) to a value of 30^o for example. This could be decided if the first holes drilled from a site demonstrate that the theoretical trajectory can be easily followed and that the safety margin can be reduced.

2.3.5.2 If the angle of a well can be increased to 15^o, one can have a high capacity storage, allowing 19 wells in fig. 4. Three of the wells are vertical, the center one and one at each end of the storage. The 16 other wells would be drilled with the paths shown on fig. 5.

The increase of capacity is not achieved at the cost of the separation between two wells, which is always higher than 120 m.

2.4 Architecture of the well

2.4.1 Most oilwells are drilled with mud, i.e. basically a mixture of water, clay and chemical additives allowing control over viscosity, pH, etc. Drilling fluids such as foam, mist, aerated mud have been used, almost exclusively when the oil reservoir is abnormally underpressured. They are therefore of no particular interest for this project, their only advantage being their specific gravity, lower than 1. Air has also been used but even with "oilwell" diameters, very large compressors are needed, since only the speed of air returning to surface gives lifting and carrying capacity for removal of formation cuttings. The use of air also creates technological problems (drilling bit design, rotating blowout preventer, etc.), emphasized by the large diameters required in this project. In the present state of the technique, air cannot therefore be regarded as a convenient drilling fluid, and one is restricted to mud.

2.4.2 The choice of a specific mud type and of mud chemical properties is governed by the nature of the formation drilled. The mud specific gravity, is adjusted to counterbalance fluid pressure in the formation.

Since it is extryemely unlikely that any formation drilled will contain hydrocarbons, mud specific gravity can be choosen at will, and should therefore be kept as low as possible (with all other parameters held constant, drilling speed decreases when mud weight increases). The drilling fluid can even, formations permiting, be reduced to plain water which, in terms of speed of penetration, is the best and by far the cheapest liquid.

2.4.3 Pending confirmation of the precise chemistry of the overlaying formations by exploratory drilling on the proposed site(s), the only formation requiring a special type of mud is the salt layer, 80 to 100 meters thick. Attempts to drill such a formation with water or water based low solids mud will result in a massive contamination of the fluid, causing caving in the salt with possible collapse of the formation above the salt. This salt should be drilled with a salt saturated base mud. All the other formations above the granite and the granite itself can be drilled with conventional low solid bentonite/polymer mud.

2.4.4 Chances are that the two limestone layers (50 - 200 m) have low fracture pressure, equivalent to a mud specific gravity of 1,1. This has been noticed in oil exploratory wells drilled in the area of interest. Drilling through these formations with higher gravity mud will cause heavy losses of mud into formations, thus causing potential hole hazards. The saturated salt base mud required for the salt layer has a specific gravity of 1,25 to 1,30. It will therefore be necessary to set one protective technical casing string below the limestone and above the salt, around 780 meters.

2.4.5 It is also necessary to isolate the unconsolidated surface formation, 0 to 50 meters, in order to avoid possible wash-out which might even endanger the drilling rig foundations. This first surface conductor can be driven into the ground with diesel or hydraulic hammer.

2.4.6 The choice of casing diameter and rock bit sizes is governed by the following considerations:

2.4.6.1 Sizes should as far as possible be "standard" ones.

2.4.6.2 If possible, the first bit diameter should be smaller than the opening of the largest rotary table, i.e. 49 1/2 inches.

2.4.6.3 The ratio of a hole diameter to the next casing string should be higher than 1,3. (For conventional drilling sizes of 8 1/2" to 26", it varies between 1,27 and 1,30).

2.4.7 Compounding these requirements, we adopt the architecture shown on fig. 6:

i.e.:
- 56" O.D. Conductor pipe to 50 m
- Drilling 48" hole to 800 m
- 36" casing at 800 m
- Drilling 30" hole to 2'000 m
- 22" casing at 2'000 m.

2.5 Drilling technique - Sequence of operations - Planning

2.5.1 Conventional tricone rock bits are not normally manufactured in diameters above 26". We shall therefore have to use mining and industrial big hole bits of flat body type, which are available in both 30" and 48" diameter, in various configurations and adapted to a wide range of formations. These bits can be supplied by all the major manufacturers of rock bits. These bits can be adapted either for direct or for reverse circulation of the drilling fluid.

2.5.2 It is generally admitted that the minimum ascending speed of the mud carrying the formation cuttings back to surface should be about 15 meters/minute if the mud has a sufficient (by oilwell standards) viscosity. On the other hand, the pumping equipment usually installed on a heavy drilling rig is limited to about 5'200 to 5'300 litres/min. Direct circulation, where the fluid is pumped down through the drill string, and returns in the annulus between hole and drill string, is therefore limited to a diameter of 26". This figure could be increased to 30" in very hard formations, where cuttings will be very small, having therefore a lower settling rate.

2.5.3 The 48" section of hole, however, will have to be drilled with reverse circulation, air lift assisted (See fig. 7: "Reverse circulation principle").

2.5.4 The sequence of operations would therefore be as follows after the rig has been skidded into a new position.

2.5.4.1 Driving 56" conductor to 50 m (if not done previously).

2.5.4.2 Cleaning the inside of the conductor using 48" bit.

2.5.4.3 Drill 26" hole to 300 m. Deviate and orientate the hole using a turbine (this equipment can be a multi-stage turbine or a hydraulic motor connected at the bottom end of the drill string with a bent joint. It permits to start a deviation and correct it if necessary in a more effective manner than other techniques). Drill to 800 m in 26", controlling and maintaining deviation and azimuth.

2.5.4.4 Change drill string for larger one needed in reverse circulation. Rig up equipment for reverse circulation.

2.5.4.5 Open 26" hole to 48", 50 to 800 m, in air-assisted reverse circulation.

2.5.4.6 Run and cement 36" casing at 800 m.

2.5.4.7 Replace mud by saturated salt base mud.

2.5.4.8 Drill 30" from 800 to 1'000 m, top of granite section.

2.5.4.9 Drill 30" hole in granite from 1'000 to 2'000 m, maintaining previous deviation and direction.

2.5.4.10 Rund and cement 22" casing at 2'000 m. Arrange well head.

2.5.4.11 Skid rig to next position. Rig up.

2.5.5 It is fairly difficult to assess accurately the time required for the drilling of one well, and obviously the results of the exploratory wells will greatly reduce the margin of error. There are, particularly, three areas where the actual duration may greatly differ from our estimate: deviation control in large diameter holes, cementing the two casing strings, and drilling through granite. It is also important to note that performance is always improved by experience, by better knowledge of the formations, and by improvements in tools and techniques when drilling numerous "identical" wells.

Fig. 8 represents the curve of depth versus time for one well, with a total duration of about 12 months.

3. TECHNOLOGICAL COMPONENTS

Having choosen a well trajectory which allows the fulfilment of the various requirements for the storage, and a drilling technique and well program adapted to both the particular diameter of the wells and the formations encountered, it remains to be verified that the equipment, tools and technology available today permit the drilling of such wells.

We shall therefore go through the various main technological components of the proposed architecture and ascertain the technical feasibility of the "Deep Drilling Concept".

3.1 Surface conductor-pipe

3.1.1 Purpose

The main purpose of the surface conductor-pipe, usually set at a depth of 20 to 30 m, is to isolate the surface layer from generally loose and unconsolidated formations, and to avoid their possible wash-out by the mud flow during further drilling operations. Such a wash-out, occuring underneath the foundations of the drilling rig, may even cause its collapse. This pipe also allows mud return at the required level above ground, without fear of the extra hydrostatic pressure causing fracture of weak surface formations. Finallly, a part of the weight of further casing strings is supported by this conductor. It is therefore important that the conductor should be firmly set, and at the right depth.

3.1.2 Pipe and connections

Pipes are generally selected in the range of diameters and thicknesses standardized by the A.P.I (American Petroleum Institute), standard 5L. Since there is no particular requirement as far as collapse or tensile strength is concerned, we select arbitrarily a 1" tickness on 56" O.D., leaving 54" ID, and weighing 850 kgf/m. The steel quality is grade A of the A.P.I, which has the following properties:

- Minimum yield strength: 30'000 psi
- Minimum tensile strength: 48'000 psi
- 0,22 % maximum carbon
- 0,90 % maximum magnesium
- 0,04 % maximum phosphorus
- 0,05 % maximum sulphur

Considering the reduced length of pipe to be run on each well, and the suggested setting technique, it is better to simply butt-weld each section of conductor-pipe on the derrick floor. Pipe can be supplied in 12 to 15 m lengths, and an automatic welding machine will perform one connection in 2 to 3 hours on the floor.

3.1.3 Conductor-pipe setting technique

Large diameter conductors can be either run into a previously drilled larger hole and cemented, just as with any further casing string, or driven into the ground with Diesel or hydraulic hammers.

3.1.3.1 Drilling method

One choice is to drill a 72" diameter hole to 50 m, using reverse circulation, air assisted technique.

One of the advantages of this method is the control (and possibly correction) of the verticality of this first string. On the other hand, this method may cause the wash-out mentioned in 3.1.1, particularly with such large diameters. It also requires the use of a particularly viscous mud. The cementing of the annulus between hole and conductor-pipe can be performed by small diameter tubes run directly in this annulus. This method allows the strongest setting of the conductor-pipe.

3.1.3.2 Driving method

Powerful hammers have been developed to allow the driving of long strings of large diameter pipes of offshore platform piles. The Diesel types of hammer feature a heavy (5 to 8 tons) piston, striking the head of the pipe 30 to 50 times per minute. The hydraulic hammers feature a much lighter and faster vibrating device (frequency up to 1000 strikes per minute). Standard penetration tests (S.P.T.) would provide the specialized contractors with the information needed to select the right type of hammer. Water jetting, or even drilling the inside of the conductor-pipe helps to increase the maximum setting depth.

If the driving method is selected, the bottom 3 m of the conductor-pipe is oversized (thickness 1 1/2") and reinforced with tungsten carbide to create a driving shoe at the edge.

3.2 Casing strings

The American Petroleum Institute standardizes casing sizes from 4 1/2" to 20" outside diameter (standard 5A), in various wall thicknesses and steel qualities. The A.P.I. supplies also, in Bulletin 5C3, the formulae needed to calculate the performances of any tubular product, the important figures to verify for a casing string being: collapse pressure, tensile strength and bursting pressure. A safety factor ("design factor") must be incorporated into the calculations, to cater for the specific conditions of any given well.

3.2.1 Steel quality

Allthough higher performance steel may be available in smaller diameter, the highest grade of steel available for 20" casing is K.55. We therefore assumed that this grade of steel could be used for the 36" and 22" casing strings selected for this concept, and checked the properties of each string using K.55's characteristics.

3.2.1.1 K.55 steel: properties

K.55 is a carbon steel, having maximum contents of 0,04 % phosphorus and 0,06 % sulphur, and the following mechanical properties:

- minimum yield strength: 55'000 psi
- maximum yield strength: 80'000 psi
- mimimum tensile strength: 95'000 psi

3.2.1.2 Other steels: properties

Should it be impossible to manufacture the 36" and 22" casing pipes in this K.55 steel which is normally standardized for a maximum diameter of 20" casing, line pipe steels and pipes can be selected from the A.P.I standards 5LS or 5LU, with a wide range of diameters, thicknesses and steel properties such as:

- steel X 70: minimum yield: 70'000 psi
  minimum tensile: 82'000 psi
- steel U 80: minimum yield: 80'000 psi
  minimum tensile: 95'000 psi

Both these steels have higher minimum yield values than the K.55.

3.2.2 36" casing string - pipe body

The casing having 36" outside diameter and 1" wall thickness, grade K.55 can be run and set at 800 m. The safety factors for all loading cases are within the permissible limits given.

3.2.3 22" casing string - pipe body

The casing having 22" outside diameter and 1" wall thickness, grade K.55 is satisfactory to withstand all loading cases and can be set at 2000 m.

3.2.4 Couplings

Since both casing diameters lie outside the range of standard casing sizes (limited to 20" outside diameter), there is no A.P.I. connection available. Therefore, the pipes will be delivered "plain ended", ready to receive (by welding) special connectors on both ends. Fortunately, various manufacturers have already designed and built special connectors for large diameter pipes (offshore drilling and production risers, platform pilings, long conductor pipes etc.) These couplings are of 3 types.

3.2.4.1 Locking dog connectors (fig. 9)

These connectors, which were primarily designed for marine risers, are attractive in that they can be re-used many times. The connection of two lengths of pipe can be achieved in less than 10 minutes, against several hours for a welded connection. Unfortunately, the locking dog types of connectors either reduce substantially (by several inches) the available opening as compared to the casing pipe, or their outside diameter is much larger (up to 10") than the O.D. of the pipe, their use requiring therefore a vastly oversized hole. They cannot, therefore, be selected for our purpose.

3.2.4.2 Threaded connectors - standard

These have been designed for long conductor pipes, and are particularly well suited for the 36" casing. They incorporate a coarse, 2 pitch tapered thread, and an "O" ring assures a pressure tight seal. This type of coupling provides an easy stab-in, quick make-up, and can of course be re-used. On the other hand, sealing is achieved only by means of an "O" ring, and we suggest limiting their use to the 36" string.

3.2.4.3 Threaded connectors - special (fig. 10)

One manufacturer has developed a special, high strength threaded pipe connectore, featuring, in 20" nominal size, 2 positive metal to metal seals. Such couplings, being designed as a "weld-on" casing connection, and featuring collapse, tensile and internal yield performances equal or superior to those of the pipe on which they are fitted, are perfectly suitable for the 22" casing.

3.2.5 Casing strings - accessories

Casing strings are always "dressed " with a variety of accessories, including:

- Shoes (either regular, float or stab-in models) made with a drillable material (cement, resin etc). They transform the sharp edge of the bottom of the casing pipe into a smooth spherical shape, allowing an easy transit of the casing even through abrupt changes of angle.
- Collars: they allow multiple stage cementing, or permit to "float" the casing being run, by restricting the amount of fluid penetrating it.
- Centralizers: Help centering the casing in the hole for a better quality cement job.

All these tolls are of rather simple design, and even though they are available today only for a maximum casing size of 20", they can certainly be manufactured for any specific casing size.

3.2.6 Casing handling

The apparent weight of the casing strings in the mud will be:

- 36" casing: $981'000 \times \frac{7.85 - 1.10}{7.85} = 843'000$ pounds or $= 422$ US short tons

- 22" casing: $1'472'000 \times \frac{7.85 - 1.30}{7.85} = 1'228'000$ pounds or $= 614$ US short tons

The weight of pipe connector is negligible. Special elevators, with 750 US short tons capacity, have already been manufactured for 24" pipe and can therefore be adapted in 22". 500 t capacity elevators are available in diameters up to 96". We can therefore safely conclude that the handling equipment for both casing strings in the concept is available.

3.3 Cementing

Cementing the annulus between a casing string and the walls of the hole fulfils a variety of purposes, such as:

- To restore the separation of the different geological formations (particularly water bearing ones) which otherwise can communicate via the hole, so as to prevent any migration of fluids between them.

- To help support the weight of the casing by bonding it to the formations.

- To prevent corrosion of the casing walls.

The quality of the cementing operation (homogeneity of the cement, quality of the bond between cement and casing and between cement and formation, etc.) has a paramount influence on the quality of the completed well.

3.3.1 The cement

The A.P.I. has standardized several types of cement, the major differences between them being:

- setting time
- temperature (i.e. depth) at which they can be used
- hardness

In addition to the different A.P.I. cements, specialised contractors have developed a large variety of additives, the most commonly used being: setting accelerators, setting retarders, friction reducers, lightweight additives, and lost circulation material. This variety of additives compounded with the choice of cement properties, allows one to design and engineer the most suitable slurry for any specific situation.

Here again, the development of deep drilling in oilfields will certainly lead to the development of new products, for example mixtures of cement and resins (or plastics), or even pure "non-cement" materials.

3.3.2 Slurry and cement volumes

3.3.2.1 Cementing 36" casing in 48" hole

The volume of the annulus between the 48" hole and 36" casing for an 800 m length is 409 m^3. In fact, the hole is likely to be oversized, and it is common practice to increase the theoretical volume by 20 - 25 %. We assume therefore a volume of slurry of 500 m^3.

Since the formations (particularly limestones) are liable to be fractured, it will be necessary to reduce as much as possible the specific gravity of the slurry. This is achieved by incorporating bentonite into the dry cement. For example to mix 500 m^3 of slurry with a specific gravity of 1,40 one requires:

- 250 t cement
- 50 t bentonite
- 400 m^3 water

3.3.2.2 Cementing 22" casing in 30" hole

The uppermost 800 m of the casing is within a 36" outer casing, the remaining 1200 m within a 30" hole. The enclosed volume is thus 525 m^3.

A major part of this volume corresponds either to an annulus between two casings or to an annulus in granite, which formation is unlikely to wash easily, so the hole should be fairly close to 30". We assume therefore a slurry volume of 550 m^3.

If we require 550 m^3 of slurry with a specific gravity of 1,85, we mix:

- 684 t cement
- 335 m^3 water

3.3.3 Surface equipment

3.3.3.1 Cement storage

Large volumes of cement are normally handled in bulks, the largest ones (3 m diameter, 9.5 m high) having a capacity of about 65 tons. A battery of 12 such large storage bulks would therefore suffice. The compressed air necessary for the transfer between bulks and mixing unit would be furnished by the large air lift compressors and pressure reducers.

3.3.3.2 Mixing and pumping equipment

Mixing is achieved via hoppers which are identical in design to the mixers used for the mud. Mixing and pumping equipment (two high pressure pumps) is generally installed on a special cementing truck, with a maximum pumping capacity of 1600 l/min/truck.

Total pumping time should, however, be limited to $\sim$2 1/2 hours, including pumping of the displacement fluid, to avoid prematurate setting.

a) Cementing 22" casing with a stinger (fig. 11)

A string of D.P. is connected to the shoe of the casing to reduce the volume of displacement fluid.

- Internal volume of 5 1/2 D.P. ~ 16 m^3
- Total volume to pump: 566 m^3
- Pumping rate: 226 m^3/h or 3,75 m^3/min.

Equipment will consist of 4 trucks (3 pumping, 1 stand-by).

Note: If the same rate of pumping is maintained throughout the operation and cementing of the 2000 m is achieved in one stage, pressures might reach high values at the end of the operation with:

- Hydrostatic overpressure of cement: 170 kg/cm^2
- Friction losses in 5 1/2 D.P. at 3,8 m^3/min: 150 - 160 kg/cm^2

b) Cementing 22" casing with plugs (fig. 11)

The cement goes down the inside of the casing, and this full internal volume has to be displaced (cement and displacement fluid being isolated by rubber plugs)

- Internal volume of 22" casing: 405 m^3
- Total volume of pump: 955 m^3
- Rate of pumping: 382 m^3/h or 6,4 m^3/min

The equipment needed is then 4 or 5 trucks pumping with 1 or 2 stand-by.

Note: A higher rate of pumping will lead to a better displacement of the mud in the annulus by the slurry, and so a better bonding of cement and formations. Also, friction losses will be much reduced since we use the full 20" diameter of the casing as compared to the 4.5" inside diameter of the 5 1/2 O.D. D.P.

c) Cementing 36" casing (fig. 11)

The volume of slurry is slightly lower. The hydrostatic overpressure of the cement will be much reduced and it is probably better to use the stinger method. However, limestone is likely to be fractured by the slurry and it will be necessary to forecast the material to complete an outside job, with for example two tubing strings to be run into the annulus 36" - 48". Here again, exploratory drilling will supply valuable information on fracture pressure, squeeze rates, possible plugging of fractures etc.

3.3.4 Quality control

The quality of the cementing operation is monitored by the cement bond log (C.B.L.), which gives valuable information on the quality of the bonding between casing and cement, and between cement and formation, and also on the degree to which channels may have developed in the cement.

3.3.4.1 Improvement of bonding

The quality of the bonding between casing and cement can be greatly improved by coating the casing before it is run with a resin/sand mixture (this technique is widely used in pipe line construction). To improve the bonding between cement and formation, one can dress the casing with wall scrapers which mechanically remove the mud cake deposited on the walls of the hole and improve contact with the formations.

3.3.5 Conclusion

For both 36" and 22" casing the cementing operations will most certainly be the most delicate operations of all those which are required in completing the wells. This is because of the high volumes of slurry and the high pumping pressures which will be required.

Laboratory testing will be needed before one can select, design or develop slurries for both strings. For example, one must investigate the effect of the heat generated by the containers on the hardness and the sealing properties of the cement, as well as the effect of time (at geological scale) on such properties.

3.4 Monitoring and piloting a well

3.4.1 Measuring equipment

Measuring equipment ranges from basic instruments, which can be used by rig personnel, to sophisticated systems, which require highly trained specialists and the assistance of a computer.

3.4.1.1 Mechanical drift indicators

These tools, which are extremely simple and rugged, use a free pendulum device to measure the inclination, i.e. the angle at a given point, between the axis of the well and the vertical at this point. They give only one recorded indication per run, and are mostly used to control the variations of inclination in "straight" exploratory holes, which are generally near-vertical. The range of inclinations measured varies from 1 - 1 1/2° to 0 - 24°. The precision for the most common 0 to 8° unit is ± 1/4°.

3.4.1.2 Magnetic instruments

These record both the inclination of the well and its direction as compared to the direction of the magnetic pole. Any measurement must naturally be made in a non-magnetic environment, and this is achieved by incorporating one or two non-magnetic drill collars (K. Monel drill collars) in the bottom hole assembly, as close to the drilling bit as possible. These tools are universally used to measure direction and inclination in deviated orientated wells. Their precision is ± 1/4° on the inclination, and ± 1/2° on the direction if the inclination is higher than 5°, otherwise it is ± 2°.

3.4.1.3 Gyroscopic instruments

These highly sophisticated tools represent the current state-of-the-art in inclination and direction measurement. They are used only by specialized personnel, and require a computer for drift correction.

One can plot the path of a well with an accuracy on any measurement of ± 2' on inclination and ± 1/2° on direction.

3.4.1.4 Future trends

Inertial navigation techniques and technology are being brought into the field of deviation measurement. Various companies are working on new tools which will monitor continuously (instead of the present step by step method) the horizontal displacement of a well, with an accuracy in the range of $\pm$ 20 to 30 cm at 1000 m.

3.4.2 Measuring techniques

All measuring tools are normally run inside the drill string at the end of a cable causing therefore a temporary shut-down of the drilling itself. The tools are either completely self contained (measuring equipment, timer, recorder) and therefore retrieved after each measurement, or the information is transmitted electrically through the cable back to the surface, allowing a complete survey of the hole in one run. Magnetic instruments are self-contained whereas gyroscopic ones feature surface recorders.

3.4.3 Piloting a well

It is important to bear in mind that:

a) any measurement can be made only after a section of hole has been drilled

b) measurement of deviation and direction is not made at the bit itself, but inside de non-magnetic drill collar, a few meters above the bottom of the hole

c) the tool is run inside the drill string, the reading at a given depth does not give direction and deviation of the hole itself, but of the drill collar the direction of which may be slightly different from the direction of the hole.

The whole process of piloting a well so as to follow a predetermined trajectory therefore involves repeated application of the following operations:

1. Drill a section of hole (for example 20 to 30 m)

2. Stop drilling, measure deviation and direction

3. Plot results and compare with desired path curve

4. If both inclination and direction of the hole are correct, drill another section of holes with the same parameters as previously, or

   Alternatively:

   4a) If either inclination and/or direction of the hole are not satisfactory, choose appropriate corrective action to bring the hole back on track.

   4b) Drill another section of hole applying the selected corrective action.

5. Stop drilling, measure, etc.

Minor corrections are achieved simply by modifying the weight applied to the bit. More severe departure from the desired path may necessitate a change in the geometry of the bottom hole assembly (position of the reamers and stabilizers). In rare cases, correction can be made only by plugging back a section of the hole and redrilling an entirely new hole.

Allthough there is some theoretical knowledge of the behaviour of a drill string (as far as deviation is concerned), the formulae incorporate a large variety of parameters, and the accuracy with which a trajectory can be followed still relies very heavily on the experience and skill of the deviation engineer.

3.4.4 Comments

It is fairly obvious that maintaining the whole length of a hole on (or close to) a given trajectory is a difficult and expensive process, whereas reaching a specific target at a given depth (for example a 20 m radius target set at 2000 m vertical depth) can be done rather easily, if one allows some freedom on the trajectory in the upper part of the hole. Instead of trying to follow at any cost the proposed path (fig 2), we suggest that the only strict requirement should be to intersect this path at 1750 m (vertical depth) with a 15 to 20 m tolerance. This procedure would guarantee the required separation between two nearby storages, and at the same time significantly reduce the cost of the hole.

3.5 Drilling fluids

The drilling fluid is the most important single factor in the succesful completion of a well, because of its effect on actual penetration, on bit life and on stability of the walls of the hole. A carefully engineered mud programm, taking into account all possible contingencies, will be planned in detail by the selected mud company. One can, however, make some general comments, whose validity (particularly where mud properties are concerned), will require confirmation from the exploratory holes.

3.5.1 Mud properties

As mentioned previously, two different types of mud will be needed.

3.5.1.1 Mud properties (0 - 800 m)

We can assume from the geological profile supplied by Nagra, that no particular problems should arise due to the nature of the formations encountered and therefore the best performance (penetration and hole stability) is likely to be achieved with a non-dispersed, low solids mud.

Main properties of this mud should be:

- Specific gravity as low as possible (1.04 - 1.07)
- Marsh viscosity around 50 seconds
- pH above 12
- Good solids control, i.e. complete elimination of drilled solids by a thorough mechanical treatment at surface

Basic components of such a mud are:

- Fresh water
- Bentonite (20 to 30 kg/m^3) to adjust viscosity
- Polymers (bentonite expanders) to control viscosity and drilled solids flocculation
- C.M.C. (Carboxymethyl cellulose) for rheological and filtration control
- Caustic soda, to control pH, is also a bactericide

3.5.1.2 Mud properties (800 - 2000 m)

The mud used to drill the salt section will have to be saturated with salt before entering this layer.

Main properties will be:

- Specific gravity as low as possible (1.25 to 1.30)
- Marsh viscosity around 40 - 45

As this mud is being used also to drill granite formations which are basically inert, all chemical properties will be governed by the drilling of the salt and subsequent anhydrite/marl section.

Basic components of such a mud are:

- Salt saturated water (brine)
- Special salt water bentonite (attapulgite), to give viscosity and carrying capacity
- Starch to control water losses
- Non-poluting additive for gel strength and viscosity control
- Caustic soda for pH
- Corrosion inhibitors

This mud is generally highly corrosive. It is therefore recommended to use corrosion indicators in the drill string and the mud tanks to monitor the effectiveness of the corrosion inhibiting treatment.

3.5.2 Mud treating equipment

3.5.2.1 Preparation

The mud preparation section consists of one or two mud hoppers occupying an area of only a few square meters, either at ground level or on top of a mud tank.

Chemical treatment of the active mud is done through the same mud hoppers.

Mechanical handling equipment (fork-lift, conveyer belt etc.) should be used to carry the sacks from the storage shelter to the vicinity of preparation area.

3.5.2.2 Mechanical treatment

The main purpose of the mechanical treatment of the mud is to eliminate as quickly and completely as possible the drilled solids. It is therefore performed on the stream of mud coming out of the hole before these solids have time to settle down in the storage or reserve tanks. The range of tools normally used on oilwells is perfectly suited for this task and the treatment section can be built on top of two mud tanks, each measuring 12 m x 3 m x 3 m.

Main components are:

- Shale shaker: vibrating metallic screens eliminate the larger particles
- De-sanders/De-silters: multicone centrifugal separators , eliminate finer particles.

3.5.3 Pumping equipment

The equipment used for pumping mud in the hole is completely different for the two alternatives, "normal" and "reverse" circulation. In normal flow the mud goes down through the drill string and up in the annulus, in reverse circulation, flow goes the other way around with the assistance of air lift.

3.5.3.1 Conventional drilling

in hole diameters smaller than 26" to 30" requires powerful slush pumps able to reach pressures in the range of 300 kg/cm^2 with a discharge volume of up to 2500 l/min, i.e. a rated power of 1600 HP per pump. Heavy duty rigs are normally fitted with two such pumps.

3.5.3.2 Reverse circulation drilling

for large diameter drilling or hole opening. Here, the compressed air is the driving force. It is only necessary to transfer the mud from the tanks to the annulus; this is achieved with centrifugal pumps.

3.5.4 Mud storage

In conventional oilwell drilling, the same mud is continuously used, pumped into the well, mechanically treated to remove drilled solids, then chemically treated to adjust its characteristics, pumped again and so on. For safety and convenience, an extra volume of 100 to 150 m^3 is usually held in reserve at the surface. New mud is added periodically to compensate for the additional volume of hole being drilled and the possible losses due to mechanical treatment.

However, our concept is based on the drilling of a number of holes at the same location. Also the drilling mud will most probably not be left in the hole after its completion (bearing in mind the corrosive properties of the salt saturated mud). It seems advisable, therefore, to recover the mud after its completion and to reuse it for the next well.

3.5.4.1 Volume to store

The volume of each well, i.e. a 48" diameter well at 800 m and a 30" diameter well at 2000 m (with a 34" section between surface and 800 m) is approximately 1000 m^3. Adding to these figures the volume of mud kept at surface and taking into account possible oversize of sections of hole, one may have to store:

- 1250 m^3 of low solid mud
- 1250 m^3 of salt saturated mud.

3.5.4.2 Storage (fig. 12)

Conventional mud storage tanks have a capacity of around 75 m^3 and are therefore not very convenient for the large volumes in question. There are two possible solutions:

a) Storage in the ground by excavating two pools, about 30 m x 8 m x 5 m and lining the walls with reinforced concrete.

b) Storage above ground in two steel tanks, for example 16 m in diameter and 6 m high.

Note 1: In both cases, it is necessary to stir the mud with conventional electric mud agitators during the storage period, to avoid settling of the solids.

Note 2: The economics of this storage will have to be assessed, particularly in the case of the rather cheap low solids mud, since the cost of energy to run the mud agitators would be significant. This must be weighed, however, against the necessity to dispose of a large volume of mud, some of it very corrosive, if it is not saved after each well.

3.5.5 Mud products storage

All the products used in the mixing of drilling mud are normally supplied in 25 or 50 kg bags, or in 50 kg drums (caustic soda). We suggest building a covered shelter (400 to 500 m^2) with a concrete floor, and a concrete alley going to the mud preparation area.

3.5.6 Conclusion

Except for the storage of large volumes of mud, which is not usually done during oilwell drilling operations, the "Deep Drilling Concept" does not necessitate any particular equipment, technique or products, others than those currently available on any modern drilling machine.

3.6 Drilling equipment

The general term "drilling equipment" covers all the machinery, down hole tools, accessories which are an integral part of the drilling rig and are supplied by the drilling contractor, and also the other tools, considered as consumables (rock bits, hole openers, reamers and stabilizer blades etc.) which are supplied generally by the operator.

3.6.1 Pumping equipment

As mentioned in 3.5.3, two conventional pumps of large rated power (1600 HP each) are sufficient to fulfil pumping requirements in 26 to 30 inch holes. For reverse circulation drilling, two large displacement, low pressure centrifugal pumps of a kind generally used for mud mixing purposes will be necessary. The air lift assistance will be given by special drilling compressors of large power which are available from several manufacturers.

3.6.2 Lifting equipment

The capacity of the heaviest lifting equipment currently available today is:

- Derrick:	1'550'000 lbs hook load
- Crown block:	1'500'000 lbs
- Travelling block:	1'500'000 lbs
- Rotary table:	1'600'000 lbs
- Drawworks (winch):	1'600'000 lbs

The weight of the 22" casing in the mud is (3.2.6) 1'228'000 lbs, and a safety factor varying from 2 to 4 is already included in the rated capacities mentioned above. One may therefore conclude that the heaviest lifting equipment available today fulfils the requirement of the concept. In addition, the trend of exploration drilling is towards deeper wells calling for even more powerful equipment. Lifting machinery with a rated capacity of 2'000'000 lbs will very likely be available within a few years.

3.6.3 Drill pipes

Two different strings will be necessary, one for the 26" and 30" drilling, the other larger, for the reverse circulation in hole opening. It is not convenient to use this larger type of drill pipe all through the well due to the weight, difficulty in handling and space occupied on the drilling floor during trips. The two strings could be as follows:

3.6.3.1 Normal drilling

Drill pipe will have to sustain the high torque due to the large diameter bit. Suitable could be a 5" pipe of 25,26 lbs/ft nominal weight, steel grade X95 or G105 (i.e. 95'000 or 105'000 minimum yield values), with oversized tool joints for better torque capacity.

3.6.3.2 Reverse circulation drilling

Special large drill pipes, to reduce pressure drop, for instance 13 3/8" O.D. pipes with special tool joints. These are preferentially used in reverse circulation drilling technique.

3.6.4 Drill collars

Here again, two different types of equipment will be required.

3.6.4.1 26" - 30" drilling

Conventional drill collars, threaded at both ends, of large (12" - 15") diameter for increased stiffness.

3.6.4.2 48" hole opening

"DONUT" type of drill collars composed of a main shaft, on which are fitted interlocking disks ("DONUTS") to provide the desired weight.

3.6.5 Drill bits and hole openers

3.6.5.1 Drilling 26", 0 - 800 m

Conventional tricone rock bits, available in various configurations suitable for soft to medium formations. Development of deep drilling is likely to produce new generations of bits for harder formations.

3.6.5.2 Hole opening 26" to 48"

Hole openers are available, with replaceable cutting cones. These cones are offered in a variety of designs to give optimum performance for each type of formation.

3.6.5.3 Drilling 30", 800 - 2000 m

The range of conventional bits does not extend beyond 26" and the choice will therefore be between:

- Drilling with a 17 1/2" bit and immediatly above, a 17 1/2" to 30" hole opener. This set up may cause a lot of torque, and choice of hardness in 17 1/2" bits is not very wide.

- Drilling with a 30" bit built on the "large diameter bit" principle, i.e. with replaceable cones fitted to a heavy plate. Here, there is enough choice in the configuration of cones to match the hardness of any formation.

3.6.6 Conclusion

The architecture of the well, the necessity to control deviation and direction of the holes and the diameters chosen for the bits justify having two sets of down hole tools, since there are two different drilling techniques involved. However, all the equipment required for these two techniques, and the lifting equipment needed for the heavy casing strings are already available "off the shelf". In any case, the manufacturers of drilling equipment, particularly of down hole tools, have shown on many occasions their willingness to participate in new endeavours and to develop special tools for unusual situations.

3.7 Well heads - Blow-out preventers (B.O.P.)

Well heads have three major purposes:

- They permit the transfer of part of the weight of the inner casings (which are of smaller diameter and thickness and are more liable to buckle) to the conductor pipe or first casing string, which, being stronger and usually cemented back to surface, offers a stronger support.
- They make it possible to seal the annulus between two casing strings; this may be necessary when one string is not cemented back to surface.
- They allow the connection of the blow-out preventer to the last casing set, with the connection having the same pressure rating as the B.O.P.

The main purpose of the blow-out preventer is to prevent an uncontrolled escape of formation fluids at the surface.

3.7.1 Well heads

Available well heads fit only A.P.I. sizes of casing and special equipment will have to be developed. However, since it is assumed that both casing strings will be cemented back to surface, sealing of the annulus can be considered as of secondary importance, and the weight transfer becomes the first parameter in the design. We, therefore, suggest an arrangement as shown in fig. 13, where a first base plate is welded onto the 56" casing to prevent any movement of this pipe, should a wash-out happen during 48" drilling. Then, the 36" casing is partly supported, through a spool n° 1, on which it is welded, by this base plate and 56" casing. Finally, part of the weight of the 22" casing is transferred by spool n° 2 to this spool n° 1.

Instead of being forged, as is customary for mass-produced oil well spools, these special spools could be made of welded steel plates.

Should it become necessary to achieve the complete sealing of an annulus, this could be done simply by the continuous welding of the casing on the spool, and then by welding the spools together.

Whenever the shapes and dimensions of the flanges are standardized by the A.P.I., one has entire freedom to select an upper flange on the 22" spool to fit whatever equipment will be installed on the wells to lower the containers.

3.7.2 Blow-out preventers (B.O.P.)

There are two basic types of B.O.P.:

- Bag type, where an annular rubber packing is forced inwards by an annular piston. This type of preventers will theoretically seal the hole on any tubular product, including hexagonal or square kelly.

- Ram type, where two steel rams, each having a rubber lined front edge, in which is cut a semi-circular groove, move one towards the other, and join to seal the well around a pipe of the diameter of the groove. Various sets of rams, having different grooves, are necessary if several different diameters exist in the drill string, since a given set of rams will seal only around one unique diameter.

3.7.2.1 Selection of a B.O.P. type

The largest available B.O.P.'s have an inside diameter of 26¾" for the ram type and 26 1/2" for the bag type, both with a service pressure rating of 2000 psi (140 kgf/cm^2). However, the body of bag type preventers is usually forged and this may create difficulties for a "one of a kind" large diameter design. It is therefore better to choose the ram type, whose body could easily be made of a welded structure.

Two different preventers will be necessary with internal diameter matching the casing on which they are fitted, i.e. 54" and 34".

3.7.2.2 Pressure rating

The A.P.I. standardizes a range of service pressure for B.O.P., i.e. the maximum allowable pressure to be applied in operation on the B.O.P. Test pressures are usually 1.5 times the service pressures. For a preventer of a given nominal diameter, there are several limiting factors to the pressure rating:

- The bursting pressure of the casing on which this preventer is likely to be installed.

- The amount of steel that can be put on the body with todays manufacturing processes.

- The strength of the connection between B.O.P. and casing. For example, 1000 psi (70 kgf/cm^2) applied in a 54" nominal diamter B.O.P. will give a reaction of 1037 tons!

We therefore suggest limiting pressure rating of the preventers to:

- 54" B.O.P.: 500 psi
- 34" B.O.P.: 1000 psi

3.7.2.3 Remark

The blow-out preventers are of paramount importance in oil drilling (an exploratory well is succesfull only when there is actually a flow of formation fluids etc.) In the deep hole concept, however, the situation is completely different:

- The very concept of the storage requires that the formations should not contain any fluid liable to migrate.

- Exploratory holes with smaller diameters will be drilled before the storage wells. These test holes will supply detailed information on the formation characteristics, eliminating completely the hazards of the oil wells.

Provided that exploratory holes reconnoitre the actual repository site, it can be assumed that the safety of the drilling operation as far as formation fluid escape is concerned is not endangered. However, in the very unlikely event of fluid escape the blow-out preventer will give an additional guarantee that such a flow can be safely controlled and contained.

3.8 Electrical logging

Electrical logging has been developed to supply accurate information on the formations drilled, e.g. fluid content, porosity, resistivity, density, etc. Down hole logging is today a basic tool for the production engineer and the geologist.

However, the tools have been developed for the oil industry, and they can be used only in the oilwell range of diameters, say 6" to 15". Even with the present trend towards deeper drilling, it is extremely unlikely that a new generation of tools for large diameter holes will be developed in the near future.

The exploratory wells, drilled in conventional "oilwell" diameters, will allow detailed investigations of all physical properties of the formations at the location of the future storage.

Should more information be needed, the center (vertical) well of the storage could be drilled first in reduced diameter, logged, then opened to storage diameter. The two outside wells could also be used for the same purpose, giving a complete and accurate picture ofthe layout of underground formations (dip, exact depth of formation boundaries, etc.)

The drilling of a pilote hole for further opening is, however, very expensive and will increase the time required for the drilling of these large holes.

4. IMPACT ON THE ENVIRONMENT

The impact on the environment of a drilling operation such as that comtemplated in our concept takes two forms:

- Pollution and nuisances
- Occupation of space

4.1 Pollution - Nuisances

The major source of pollution is the mud and the most important nuisance is the noise generated by the drilling rig.

4.1.1 The mud

We have seen already that the mud, and more particularly the salt saturated mud, could be reused from well to well, thereby solving the problems linked with the disposal after each well of a large volume of corrosive fluid.

Naturally, during the drilling operations, it is impossible to completely prevent leakages and spills. These are usually collected below the rig, in the cellar. We suggest a cellar arrangement, as shown on fig. 14, with reinforced concrete walls (to ensure good stability and watertightness of walls). The mud collected at the bottom of the cellar is pumped and either dumped or returned to the normal circuit.

The length of time required by the completion of the total number of storage wells justifies the setting of the mud tanks on a concrete slab surrounded by a coaming, allowing easy recovery of any spills from the tanks.

4.1.2 The cuttings

Formation cuttings recovered near the mud treatment tanks can be collected in a large and low steel tank, from which they will be later removed. If required, they could even be washed before disposal (it is common practice to wash the cuttings when drilling with an oil base mud).

4.1.3 The noise

Most modern drilling rigs are diesel electric driven, and the total power of the diesel engines can reach 5'000 to 6'000 horse power.

The power could however be supplied directly from the existing electrical network, and the power plant could be limited to 2 emergency diesel electric groups.

If the drilling site is in an urban area, noise can be further reduced by the use of noise absorbing structures to meet environmental standards.

4.2 Occupation of space - Drill site arrangement

Fig. 15 shows the drill site arrangement (with the 9 wells storage of fig. 3), occupaying roughly 160 m x 70 m, i.e. 1 hectare of land.

4.2.1 Site preparation

Will include digging and preparing both mud storages and cellars, laying rig skidding beams, erecting mud sacks storage, spares and miscellaneous storage shelters, and preparing access roads to the site.

4.2.2 Access roads to the site

Must be open throughout the year for transportation of cement, casings and mud products. Oilfield transportation is usually perfomed by heavy duty trucks (heaviest load 40 tons, largest one 12 m long x 3 m wide).

Remarks: As the drilling rig will stay for several years on the same location and then will be replaced by the container handling equipment, the site will be active for many years, Particular care must be taken in building and designing.

CONCLUSION

This feasiblity study demonstrates that:

1. It is possible to conceive of an underground storage for highly active wastes, where a number of wells is drilled from a relatively small drilling site. These wells, after an initial vertical section, are then deviated and orientated in such a way that:

   1.a. deviation does not hamper any subsequent operation to be performed in the holes,

   1.b. the requirements for a nominal separation between two nearby wells are easily fulfilled, with an ample safety margin.

2. It is possible to devise an architecture for each well, taking into account the nature of the formations and the proposed drilling technique and the requirement for a 20" inside diameter casing set at 2'000 m.

3. The major part of the equipment necessary to perform the drilling operations (drilling rig, pumping equipment, down hole tools, etc.) is standard equipment, available from various manufacturers. Tools or pieces of equipment which are not available today (namely casing strings, accessories for casings, blow-out preventers) are, in our concept, mere developments or extrapolations of existing ones, and they could be manufactured immediately if needed. Historically, the drilling industry as a whole, and particularly the manufacturers, have demonstrated readiness to venture into new projects and develop new tools for specific problems.

4. It is possible to design the drilling site and the components of the drilling rig so as to reduce to a minimum all pollution and nuisances caused by the operations.

Therefore, we can safely conclude that the technology to drill a large diameter hole requested for the "Deep Drilling Concept" for the storage of high activity wastes is feasible and that it does not require any major modifications of proven oilfield equipment or techniques.

However, the very size of the project and the paramount importance of its goals will justify a sustained effort in the engineering and the planning of the various operations.

5. DEPTH LIMITS

5.1 Cased hole

The architecture of the well as described in chapter 2., the lifting equipment available, and the performance of the selected terminal casing string would permit the setting of this casing at a depth of 2'400 m with some adjustment of the design factors.

At this depth, the stress in the casing would be very close indeed to the minimum guaranteed yield value for stell K.55, and particular care should be taken while running and cementing the casing, in order to avoid abrupt variations of pressure, which might cause collapse.

At the same depth, a higher grade of steel would naturally be more satisfactory.

5.2 Uncased hole

It is possible that the containers coud be run and sealed directly inside the formation without running the 22" casing. In this case, where the repository formation (granite) gives sufficient guarantee of stability, the hole will again have a 20" diameter. The architecture of the well could become (fig. 16):

- 56" casing set at 50 m.
- Drilling 48" hole to 800 m.
- 36" O.D. casing set at 800 m.

Up to this point, the architecture of the well and the planning of operations are identical to those previously set for.

- Drilling 30" hole to 1'200 m.
- Setting 24" O.D. casing at 1'200 m.
- Drilling 20" hole to total depth.

When compared to the architecture previously described, this alternative offers several interesting advantages:

5.2.1 The use of the salt saturated mud is limited to the drilling of a 400 m long section. The volume of mud necessary is reduced, as is also the length of time for which it is used.

...

5.2.2 The 24" casing isolates the salt layer, and also the (weathered) top of the granite section.

5.2.3 The granite section is drilled with plain water with a smaller diameter than previously, and penetration will be increased substantially.

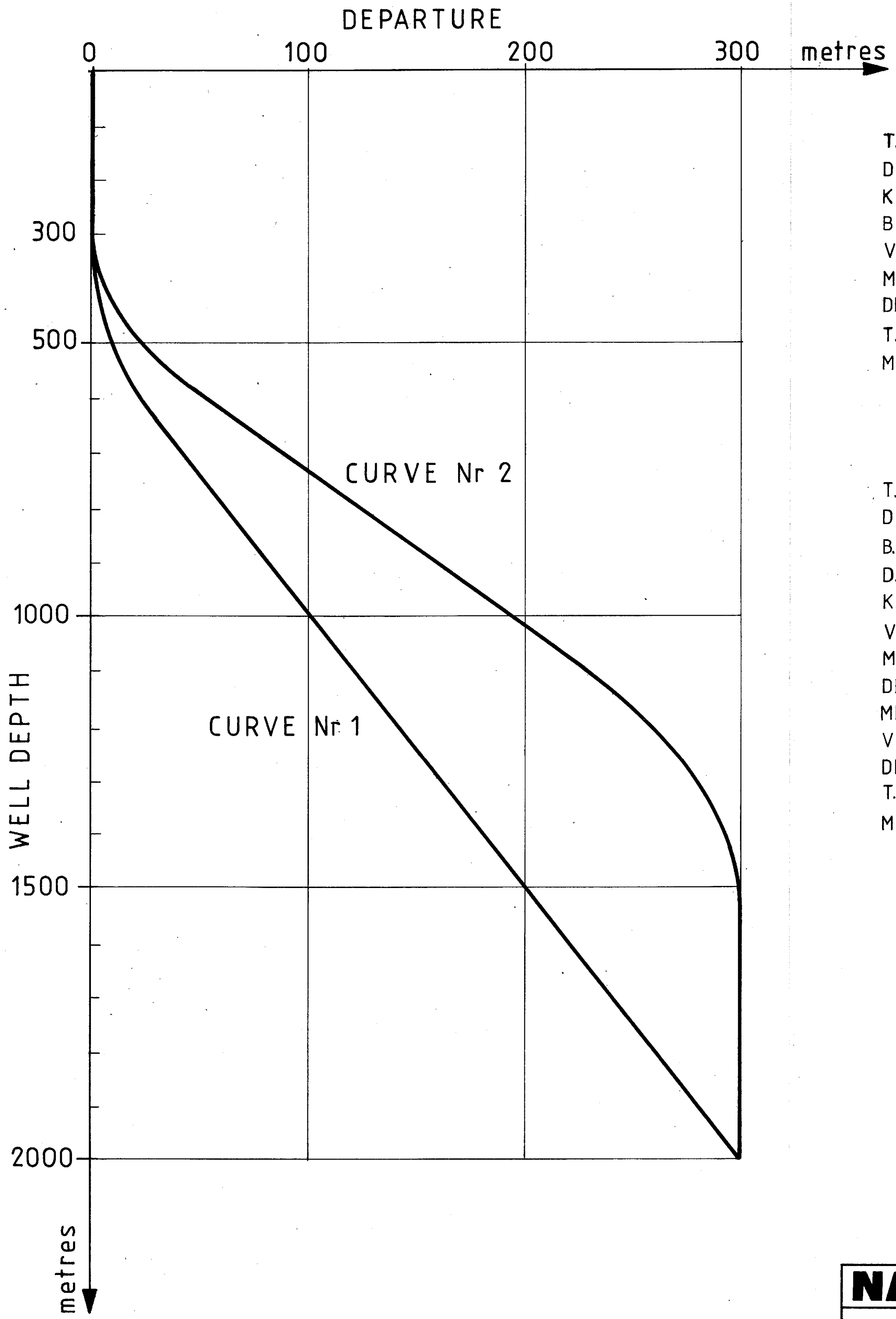
5.2.4 The most important gain is in the depth that can be reached. As it is no longer limited by casing performance or capacity of lifting equipment it can be increased to 3'000 m and more. Granite walls of the hole should offer absolute stability and such a hole could certainly be left several years without casing in.

5.3 Conclusion

The depth of the wells drilled and cased as discussed in the bulk of this study can be increased to a maximum of about 2'400 m. At this depth, all surface equipment still retains a satisfactory safety margin and the casing strings have reasonable design factors.

Should it, however, be necessary to extend the depth of wells beyond 2'400 m, this could be achieved only with a completeley new architecture of the well, where the bottom part and more specifically the storage zone would be uncased. A depth of 3'000 m and more could then be reached with this new program.

Remarks: We stress again the fact that all previous comments like the entire feasibility study, are based on the use of 1979 tools and techniques, and that any specially manufactured product (particularly higher A.P.I. steel grades for the casings) will either improve the design factors or extend the depth to which it is possible to drill and case a well.



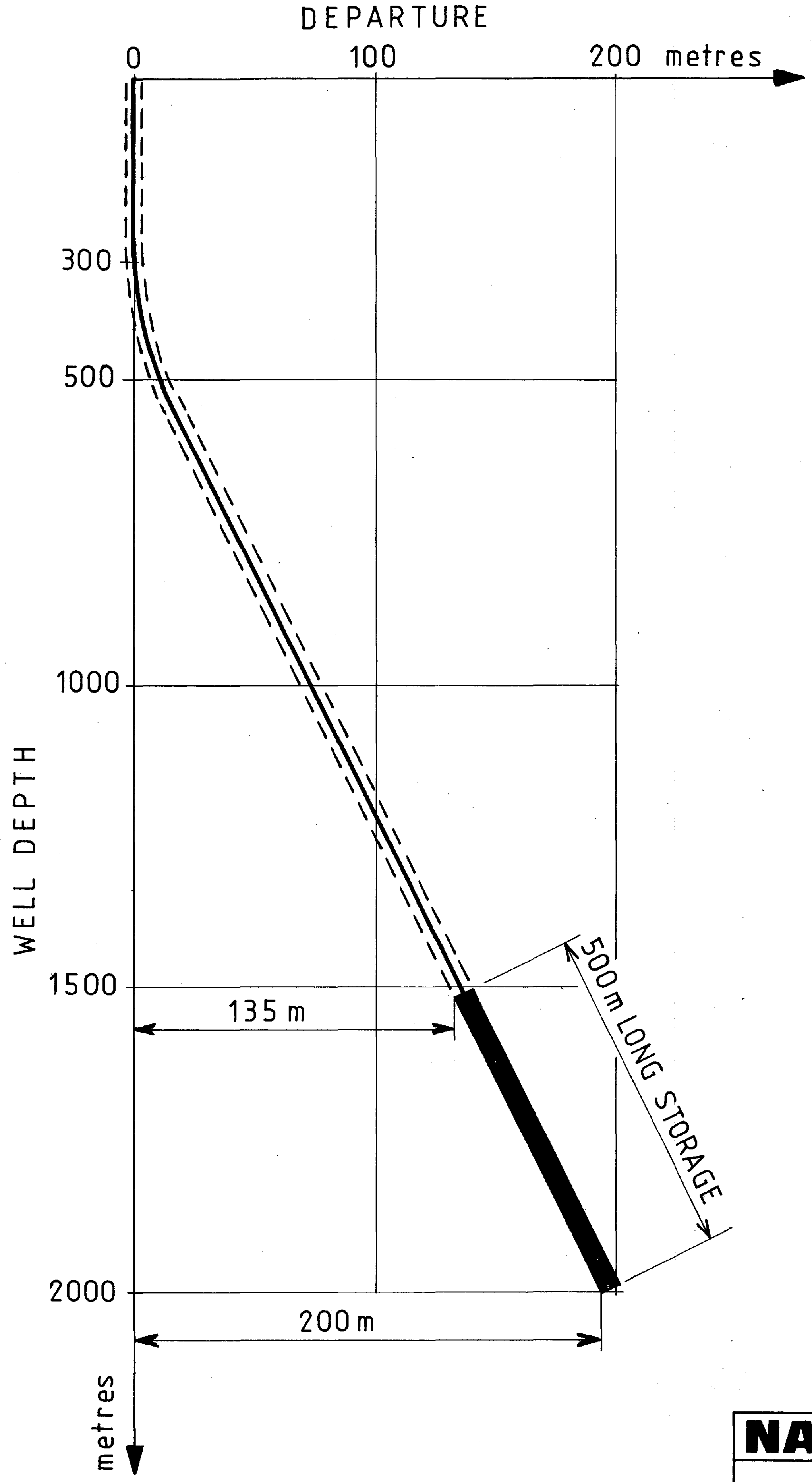
CURVE Nr 1

T.V.D.	2000
DEPARTURE	300
K.O.P.	300
B.U.R.	1°/30
VD AT FINISH OF BUILD UP	630.00
MD AT FINISH OF BUILD UP	632.07
DEPARTURE AT FINISH OF BUILD UP	31.98
T.M.D.	2028.03
MAXIMUM ANGLE	11°07'

CURVE Nr 2

T.V.D.	2000
DEPARTURE	300
B.U.R.	2°/30
D.O.R.	1½°/30
K.O.P.	300
VD AT FINISH OF BUILD UP	582.93
MD AT FINISH OF BUILD UP	588.31
DEPARTURE AT FINISH OF BUILD UP	47.91
MD AT BEGINNING OF DROP OFF	1160.00
VD AT BEGINNING OF DROP OFF	1122.75
DEPART. AT BEGINNING OF DROP OFF	236.12
T.M.D.	2044.42
MAXIMUM ANGLE	19°22'

NAGRA		**TECHNISCHER BERICHT NTB 80-04**
EXAMPLE OF DEVIATED WELLS		
FOREX	DAT.: SEPT.80	**BEILAGE 1**



T.V.D.	2000 m
DEPARTURE	200 m
K.O.P.	300 m
B.U.R.	1°/30 m
MAXIMUM ANGLE	7°05'
V.D. AT FINISH OF BUILD UP	514.19 m
M.D. AT FINISH OF BUILD UP	514.75 m
DEPART. AT FINISH OF BUILD UP	13.40 m
T.M.D.	2012.23 m

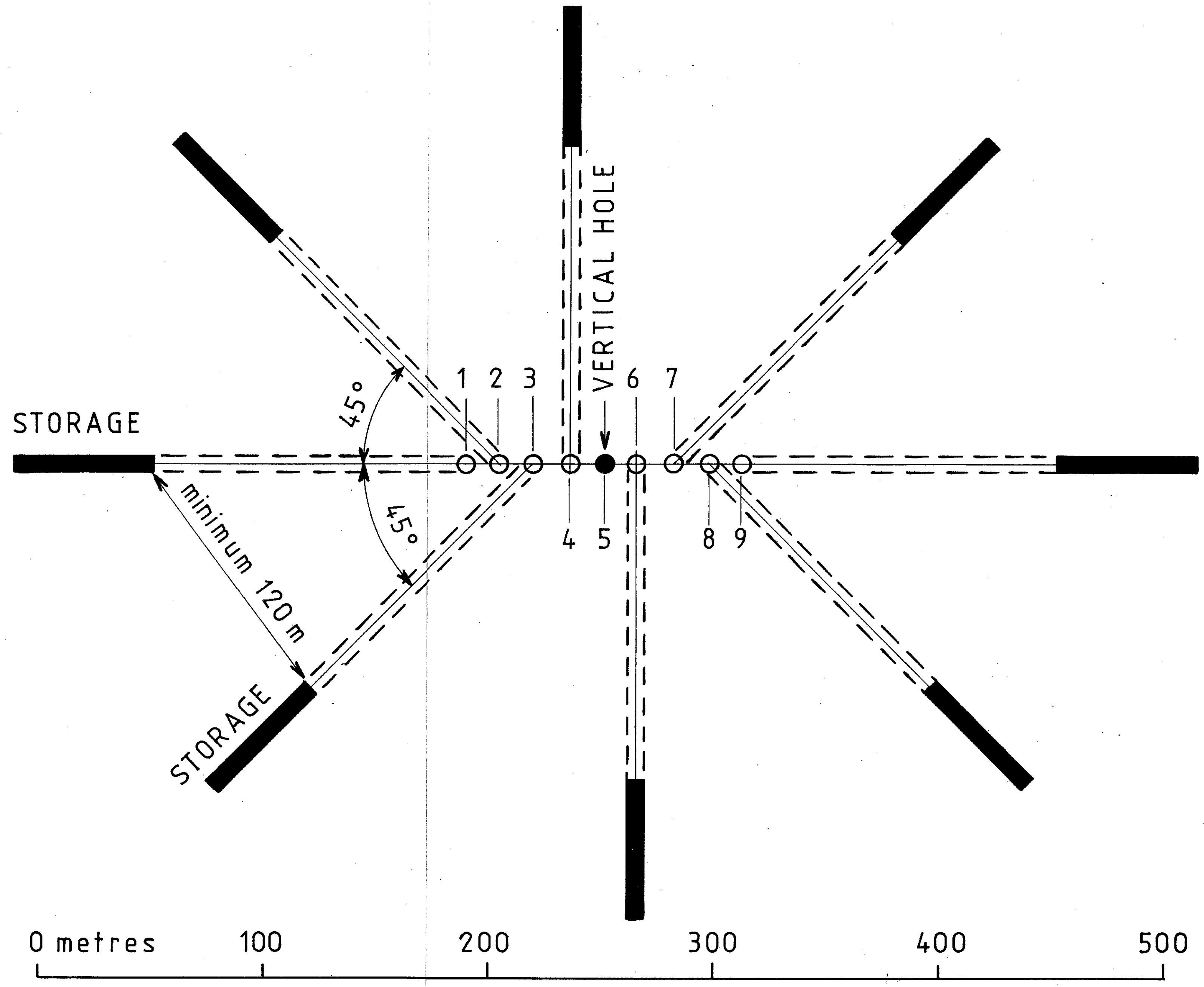
NAGRA TECHNISCHER BERICHT NTB 80-04

SUGGESTED WELL PATH

FOREX | DAT.: SEPT. 80 | BEILAGE 2

NOTA

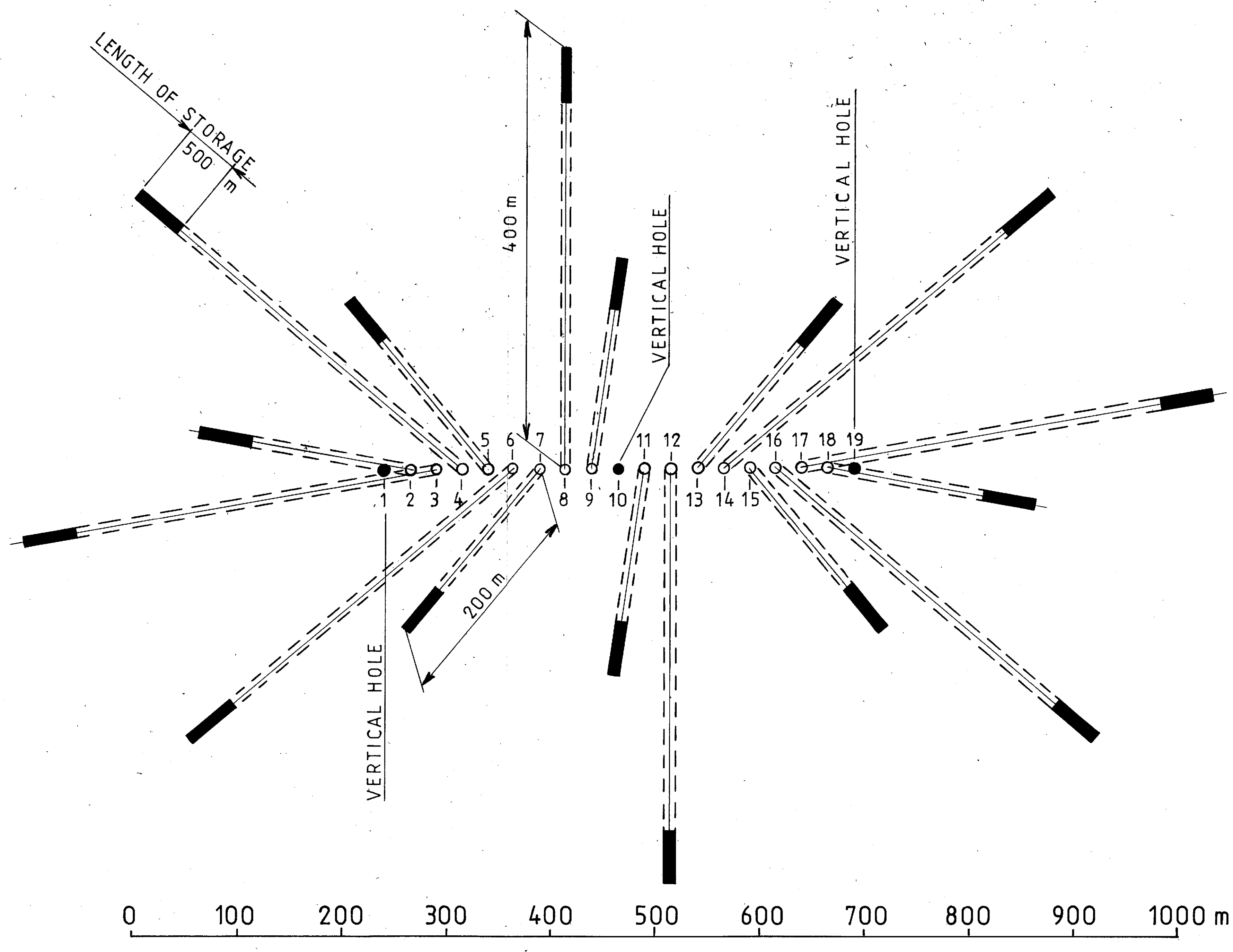
for easier reading
wells are shown with
15 m spacing at surface



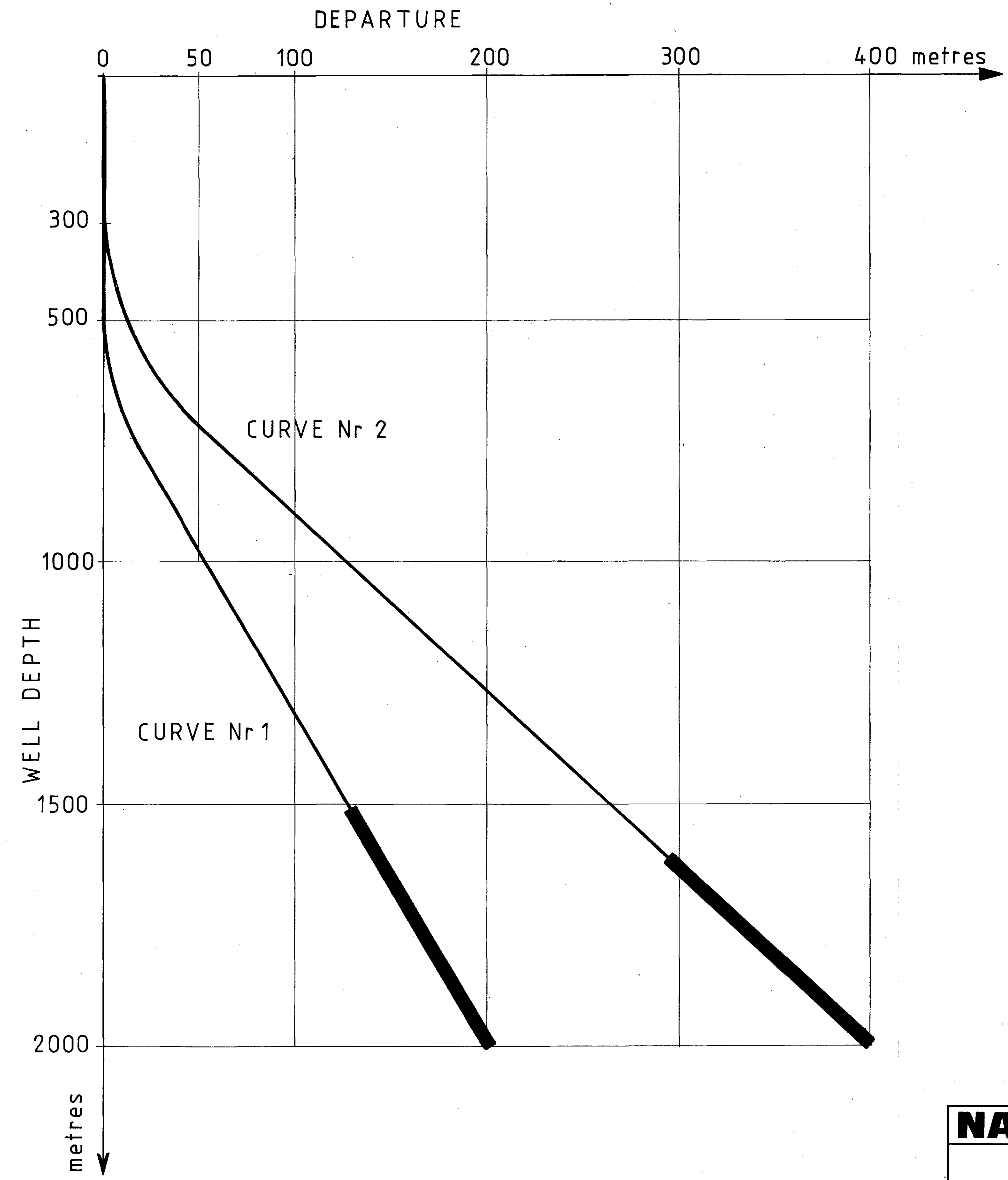
NAGRA	TECHNISCHER BERICHT NTB 80-04	
STORAGE ARRANGEMENT		
FOREX	DAT.: SEPT.80	BEILAGE 3

NOTA

for easier reading
wells are shown with
25 m spacing at surface



NAGRA	TECHNISCHER BERICHT NTB 80-04	
ALTERNATE: HIGH CAPACITY STORAGE		
FOREX	DAT.: SEPT. 80	BEILAGE 4



CURVE Nr 1

T.V.D.	2000
DEPARTURE	200
K.O.P.	500
B.U.R.	1°/30
MAXIMUM ANGLE	8°/27
V.D. AT FINISH OF BUILD UP	747.29
M.D. AT FINISH OF BUILD UP	748.15
DEPART. AT FINISH OF BUILD UP	17.88
T.M.D.	2014.03

CURVE Nr 2

T.V.D.	2000
DEPARTURE	400
K.O.P.	300
B.U.R.	1°/30
MAXIMUM ANGLE	15°22'
V.D. AT FINISH OF BUILD UP	751.20
M.D. AT FINISH OF BUILD UP	756.55
DEPART. AT FINISH OF BUILD UP	60.28
T.M.D.	2050.73

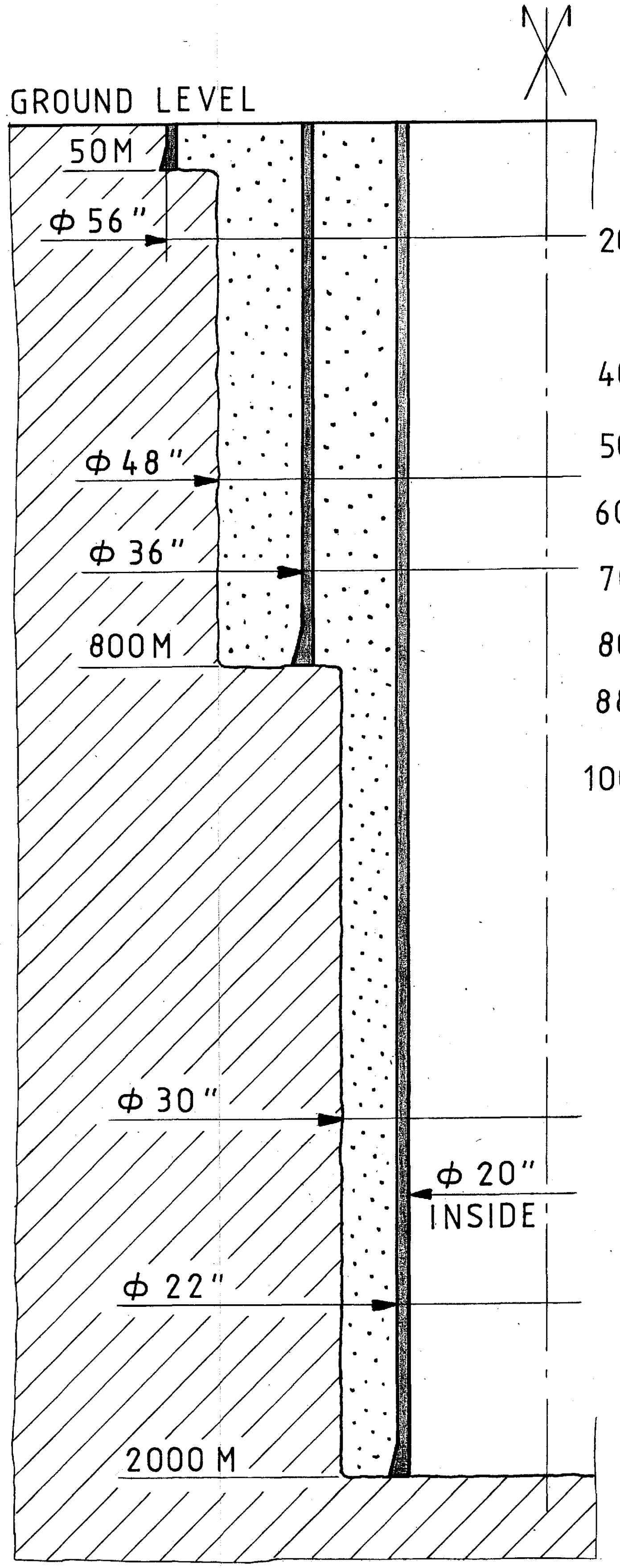
NAGRA TECHNISCHER BERICHT NTB 80-04

ALTERNATE WELLS PATHS

FOREX

DAT.: SEPT. 80

BEILAGE 5

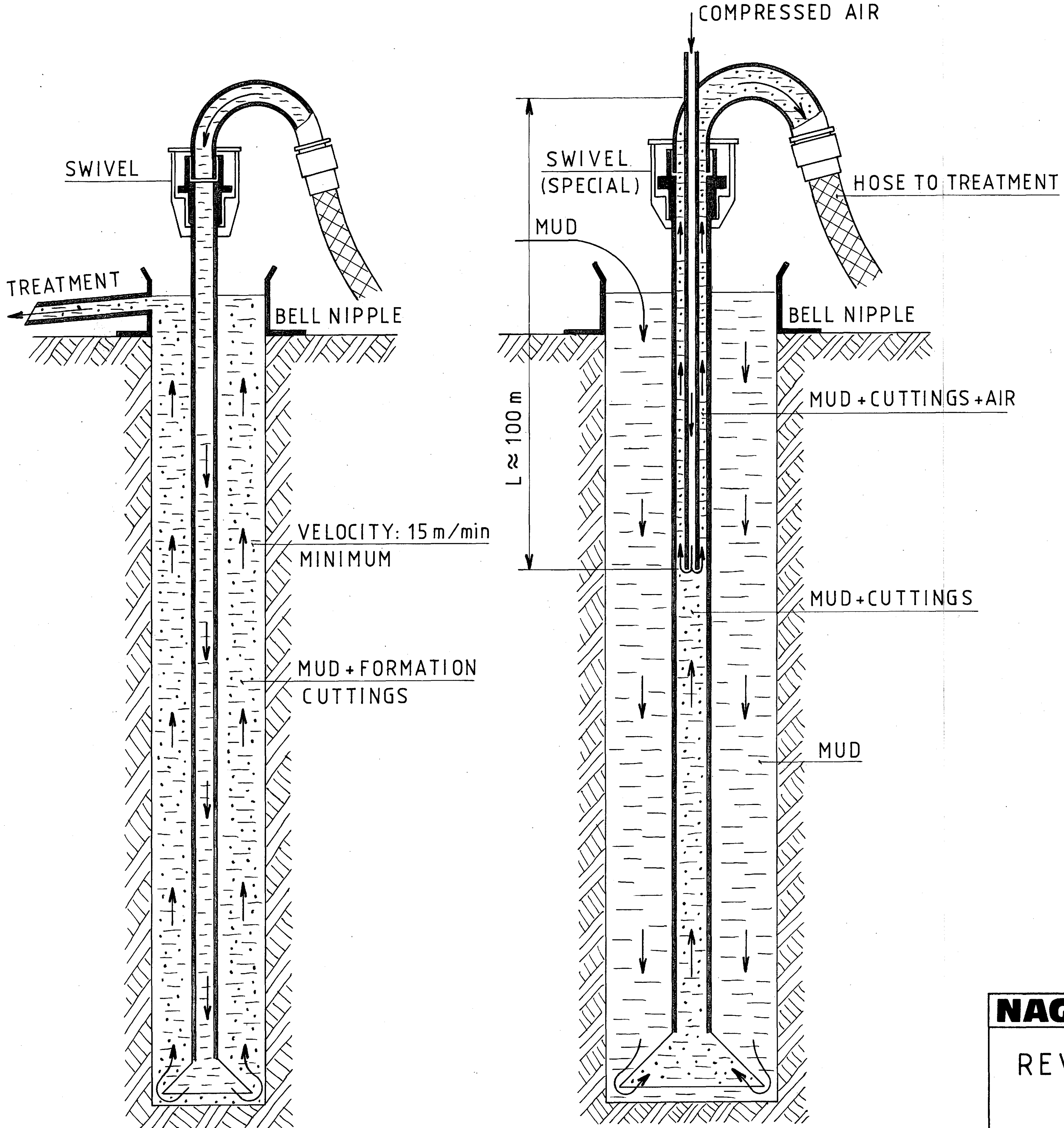


	REMARKS	GEOLOGY
50 M	UNCONSOLIDATED	SANDS
200 M	PROBABLE LOSSES	LIMESTONE
400 M		MARL
500 M	PROBABLE LOSSES	LIMESTONE
600 M		MARL
700 M		CLAYSTONE
800 M		MARL/ANHYDRITE
880 M		SALT
1000 M		MARL/ANHYDRITE
		GRANITE

NAGRA TECHNISCHER BERICHT NTB 80-04

ARCHITECTURE OF A WELL

FOREX DAT.: SEPT. 80 **BEILAGE 6**

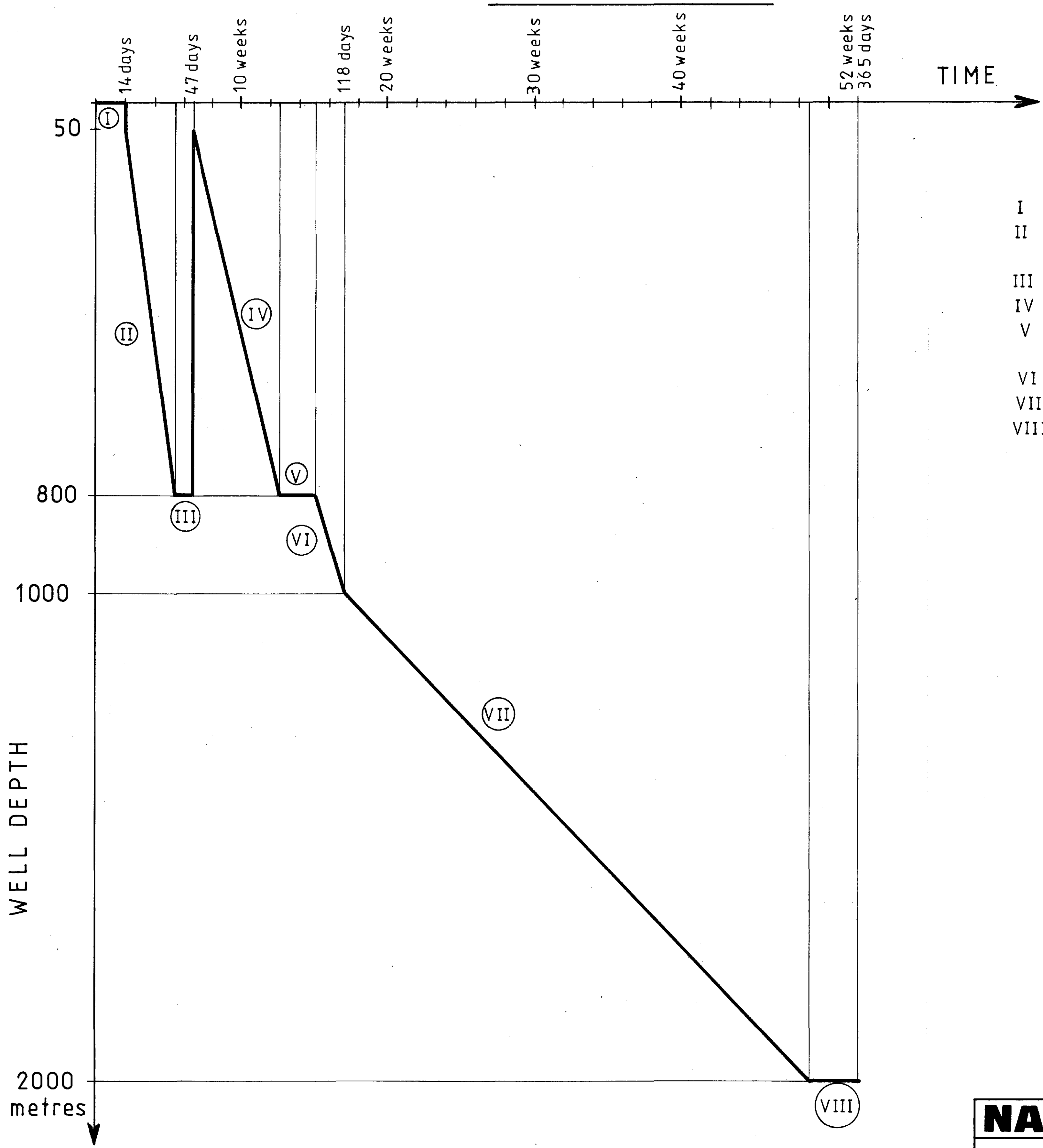


CONVENTIONAL DRILLING
HOLE DIAM. ≤ 30"

AIR ASSISTED REVERSE CIRCULATION
HOLE DIAM. ≥ 30"

NAGRA	**TECHNISCHER BERICHT NTB** 80-04
REVERSE CIRCULATION PRINCIPLE	
FOREX	DAT.: SEPT. 80 **BEILAGE** 7

PENETRATION CURVE



		EST. DURATION
I	DRIVING 56" CONDUCTOR	14 days
II	DRILLING 26" HOLE, 50 to 800 m (includes deviation)	25 "
III	CHANGE DRILLING ASSEMBLY	8 "
IV	OPEN HOLE, 26" to 48", 50 to 800 m	42 "
V	RUN AND CEMENT 36" CSG (Change mud and drilling assembly)	17 "
VI	DRILL 30", 800 to 1000 m	12 "
VII	DRILL 30", 1000 to 2000 m	223 "
VIII	RUN AND CEMENT 22" CSG	24 "
		365 days

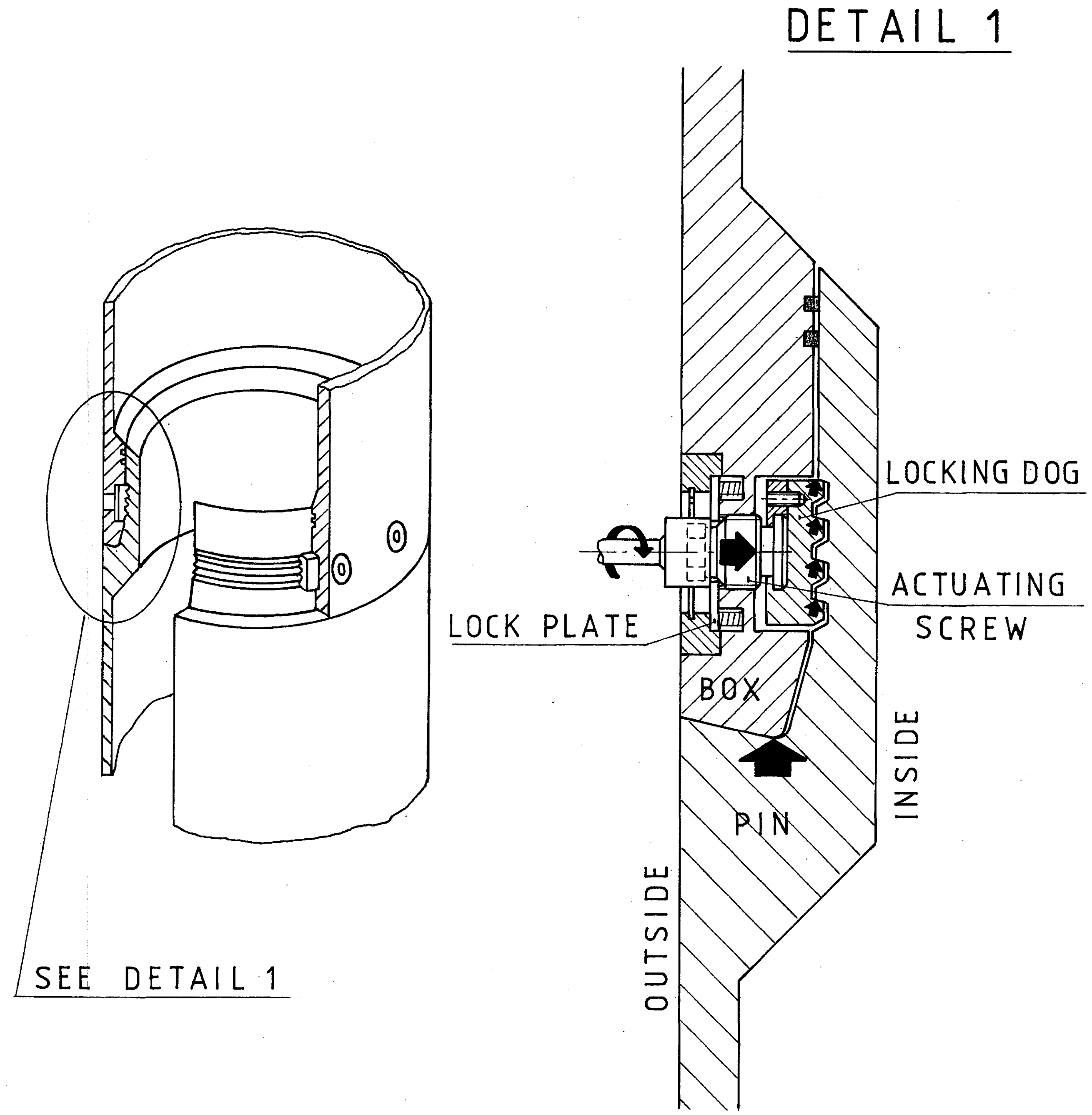
NAGRA TECHNISCHER BERICHT NTB 80-04

PLANNING

FOREX

DAT.: SEPT.80

BEILAGE 8



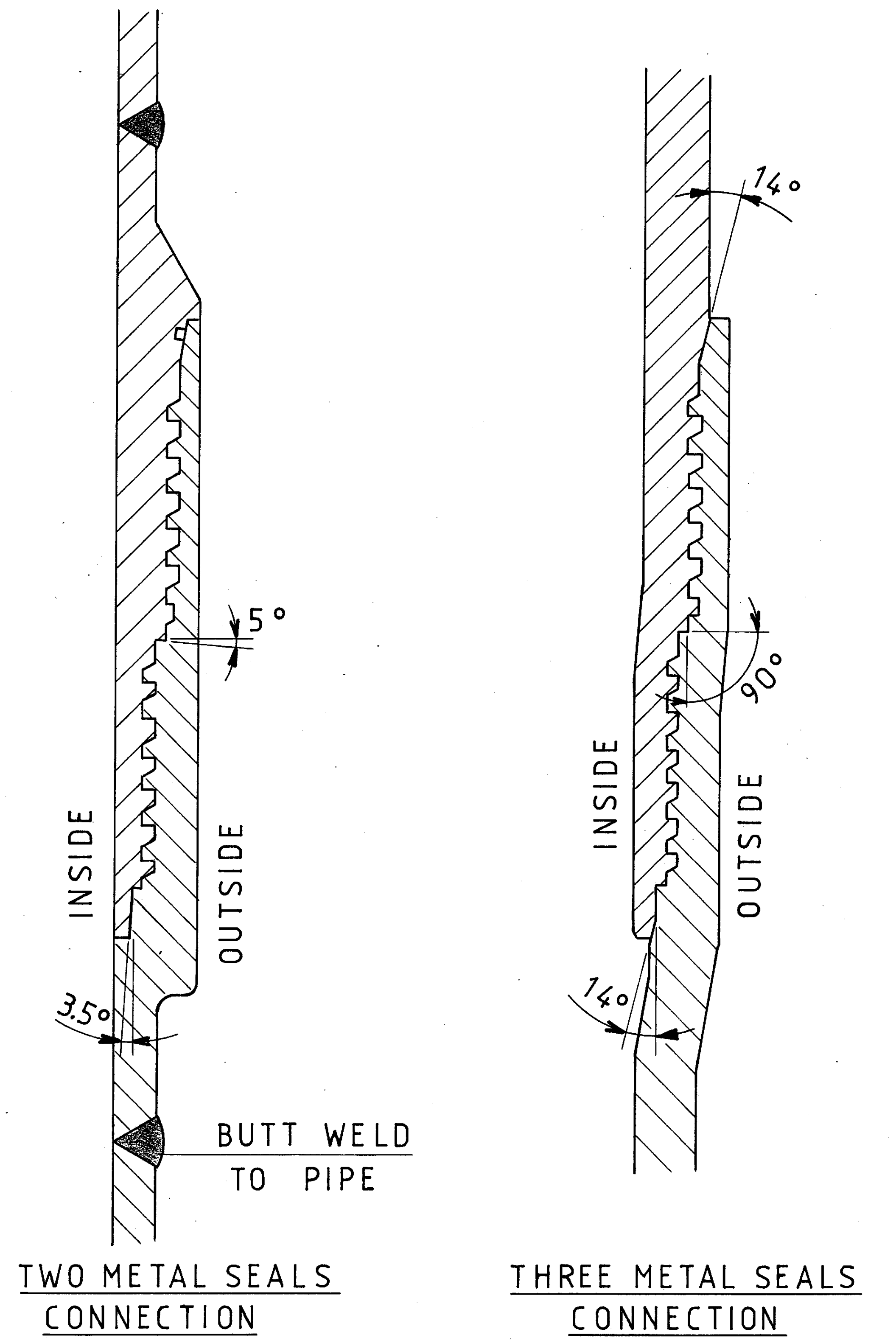
NAGRA TECHNISCHER BERICHT NTB 80-04

LOCKING DOG CONNECTORS

FOREX

DAT.: SEPT. 80

BEILAGE 9

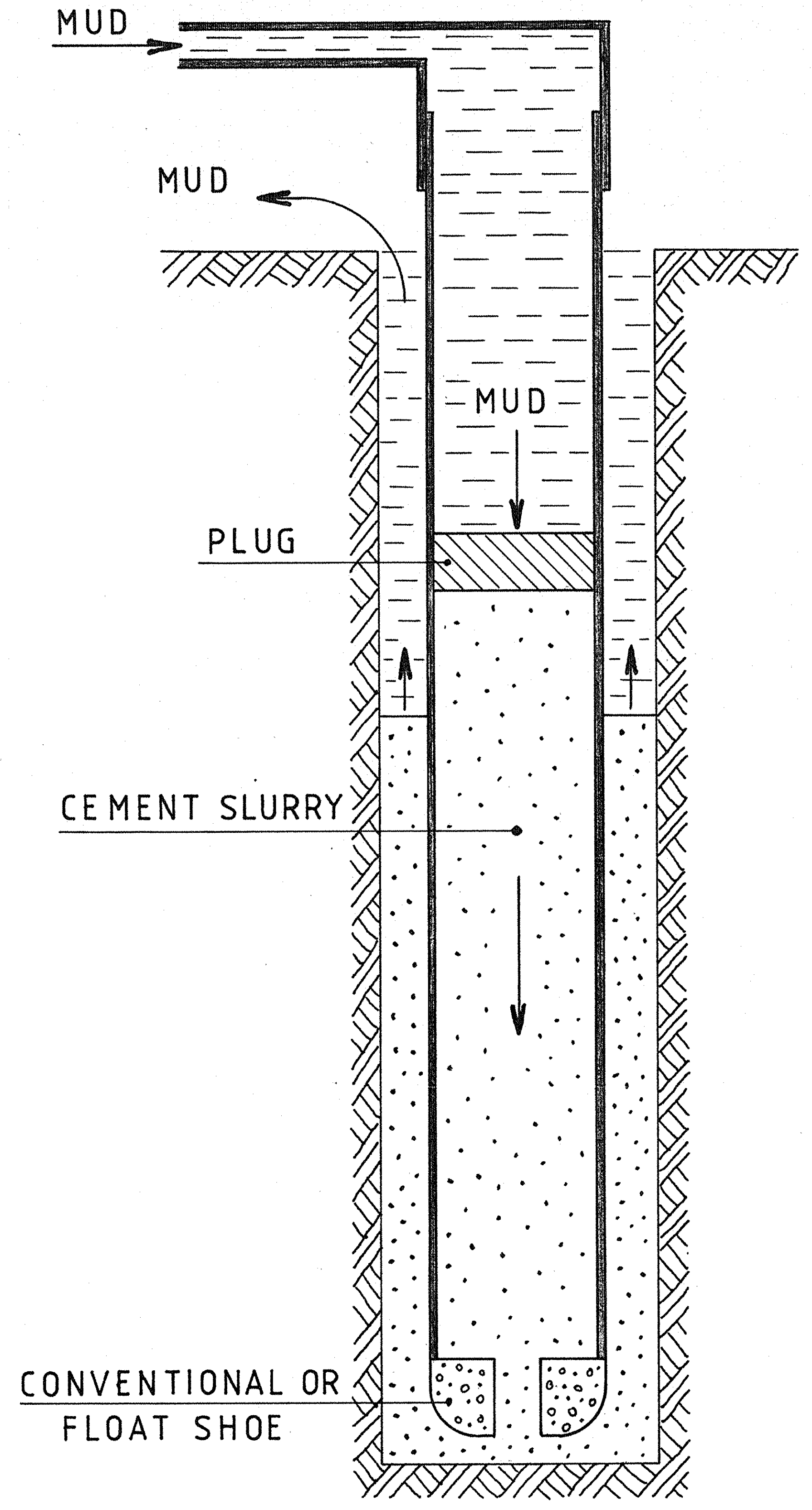


NAGRA TECHNISCHER BERICHT NTB 80-04

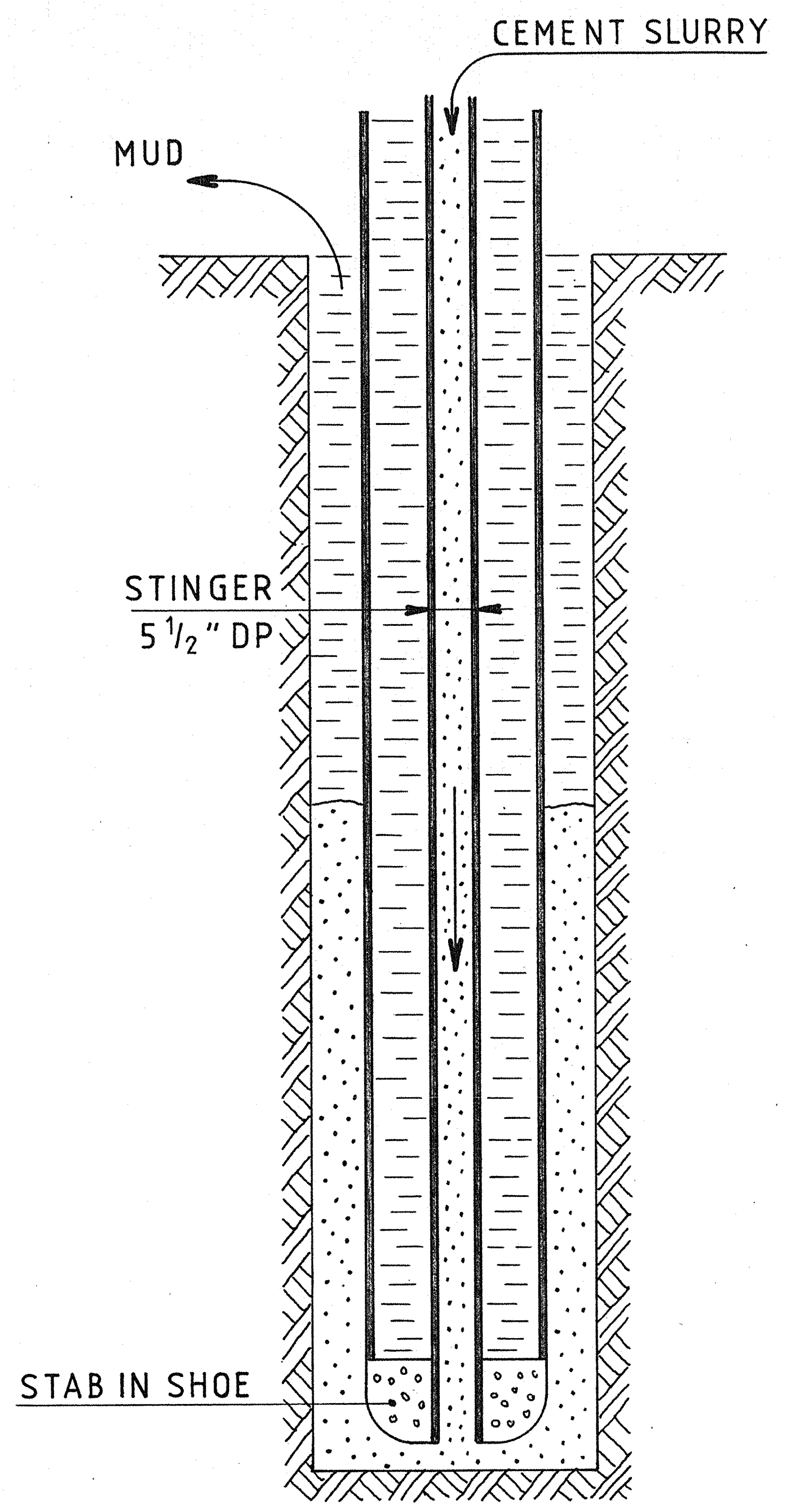
SPECIAL CONNECTORS

FOREX | DAT.: SEPT. 80 | BEILAGE 10

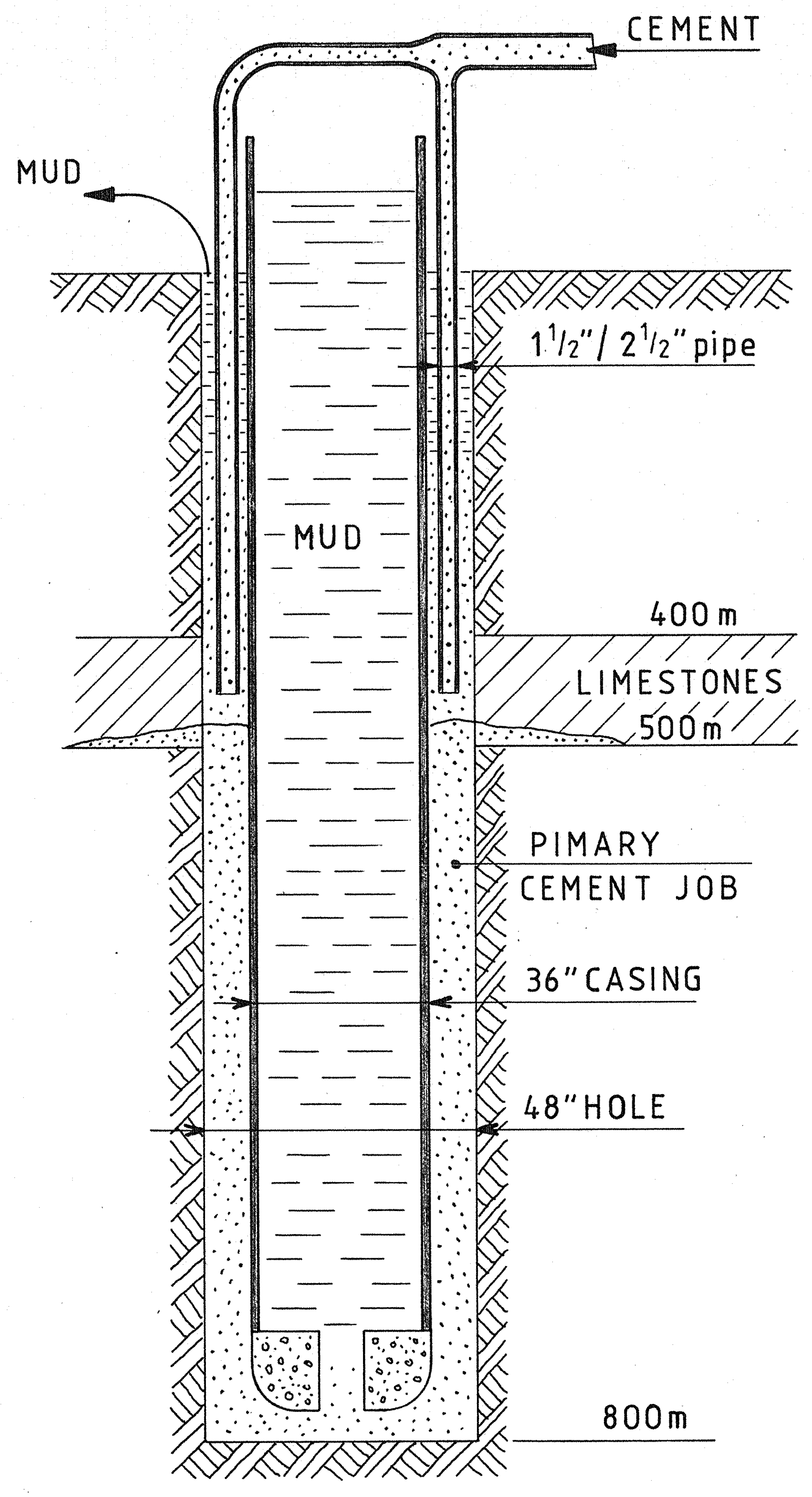
NOTE: WITH SPECIAL COILED TUBING OF SMALL DIAMETER, DRILLING COULD PROCEED WHILE ADDITIONNAL CEMENT JOB IS IN PROCESS



CEMENTING WITH PLUG

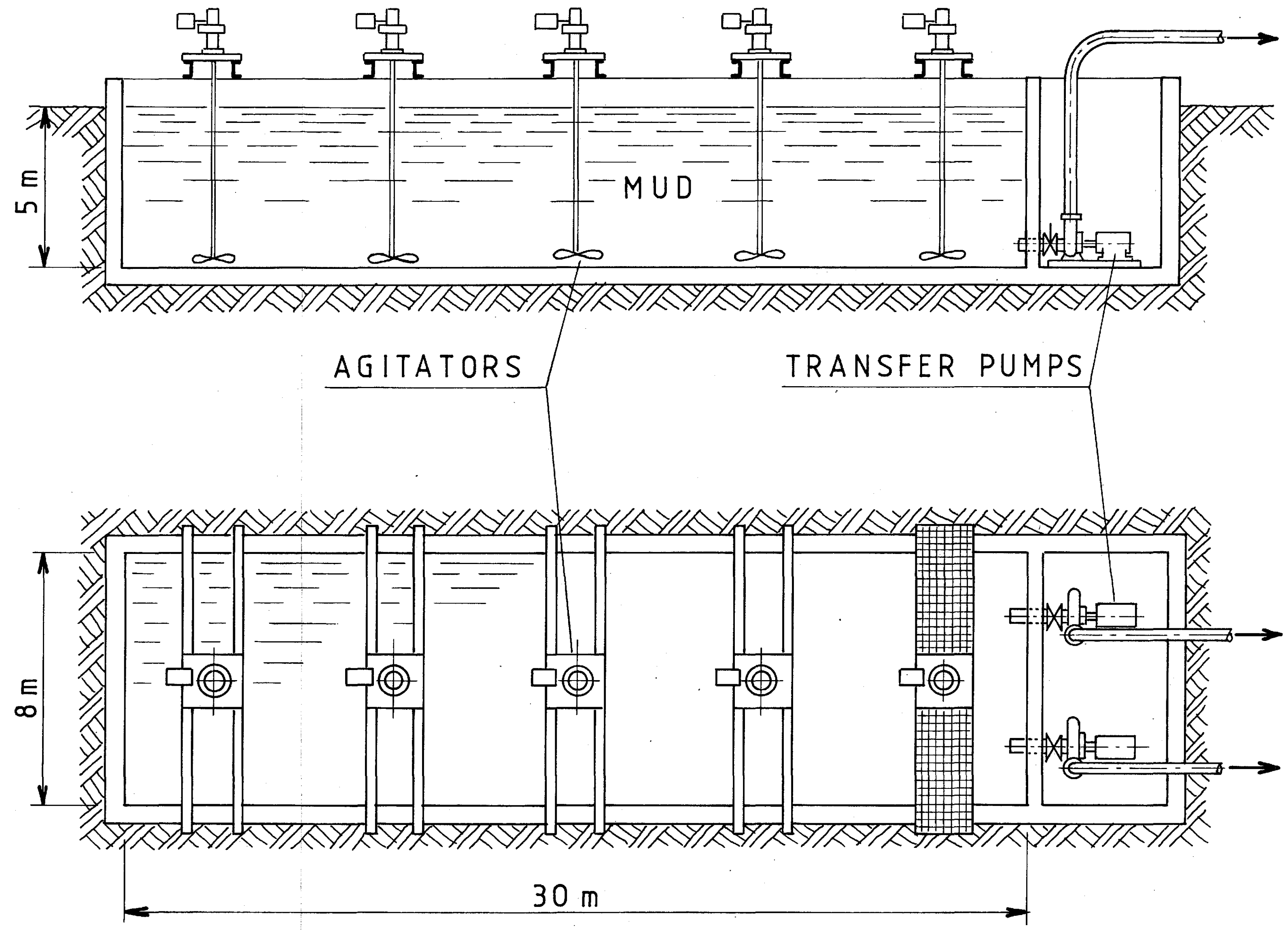


CEMENTING WITH STINGER

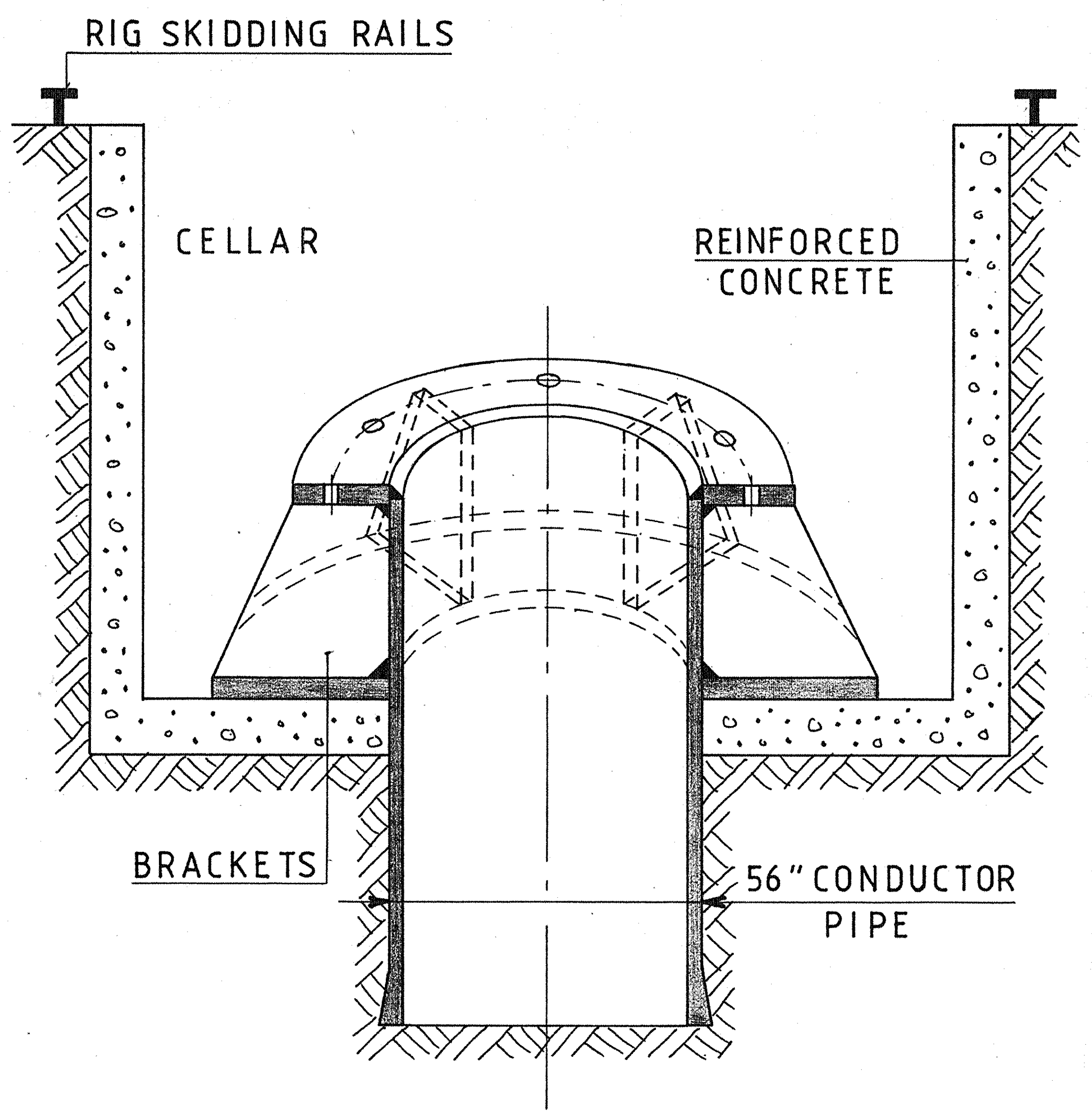


ADDITIONAL CEMENT JOB IN ANNULUS

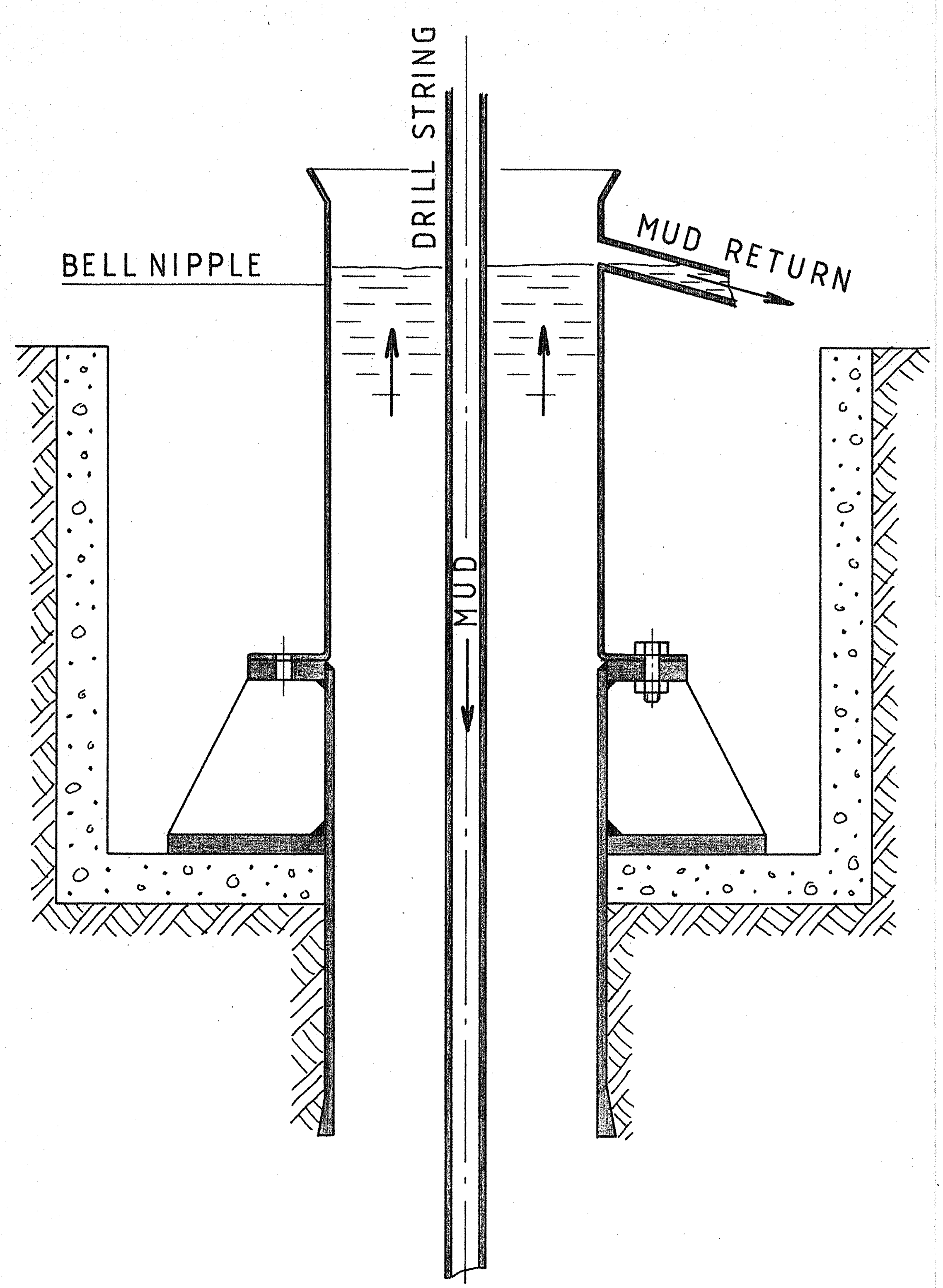
NAGRA	TECHNISCHER BERICHT NTB 80-04
CASING CEMENTING	
FOREX	DAT.: SEPT. 80 — BEILAGE 11



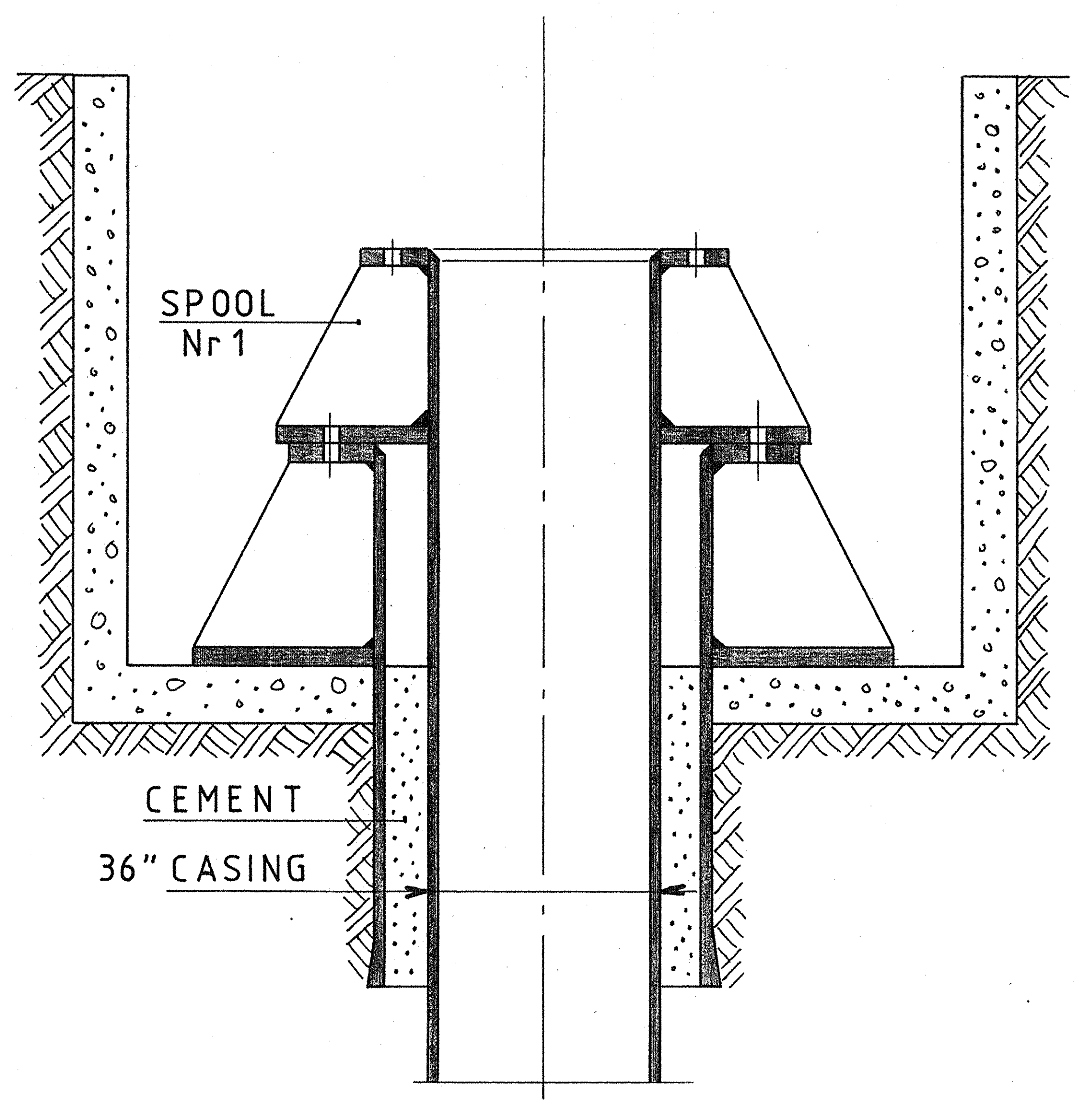
NAGRA	TECHNISCHER BERICHT NTB 80-04	
MUD STORAGE		
FOREX	DAT.: SEPT. 80	**BEILAGE** 12



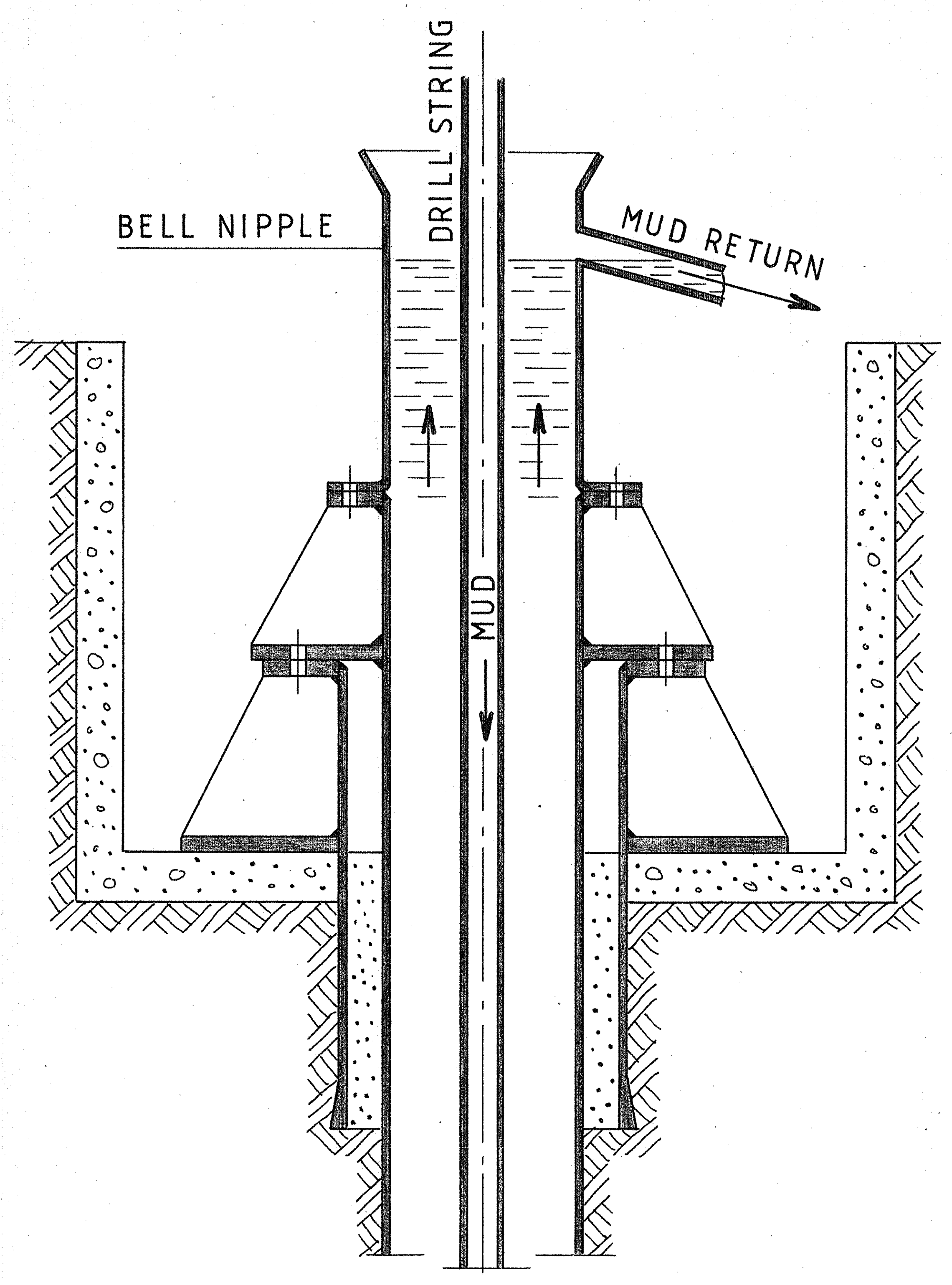
SETTING BASE PLATE ON 56" CSG



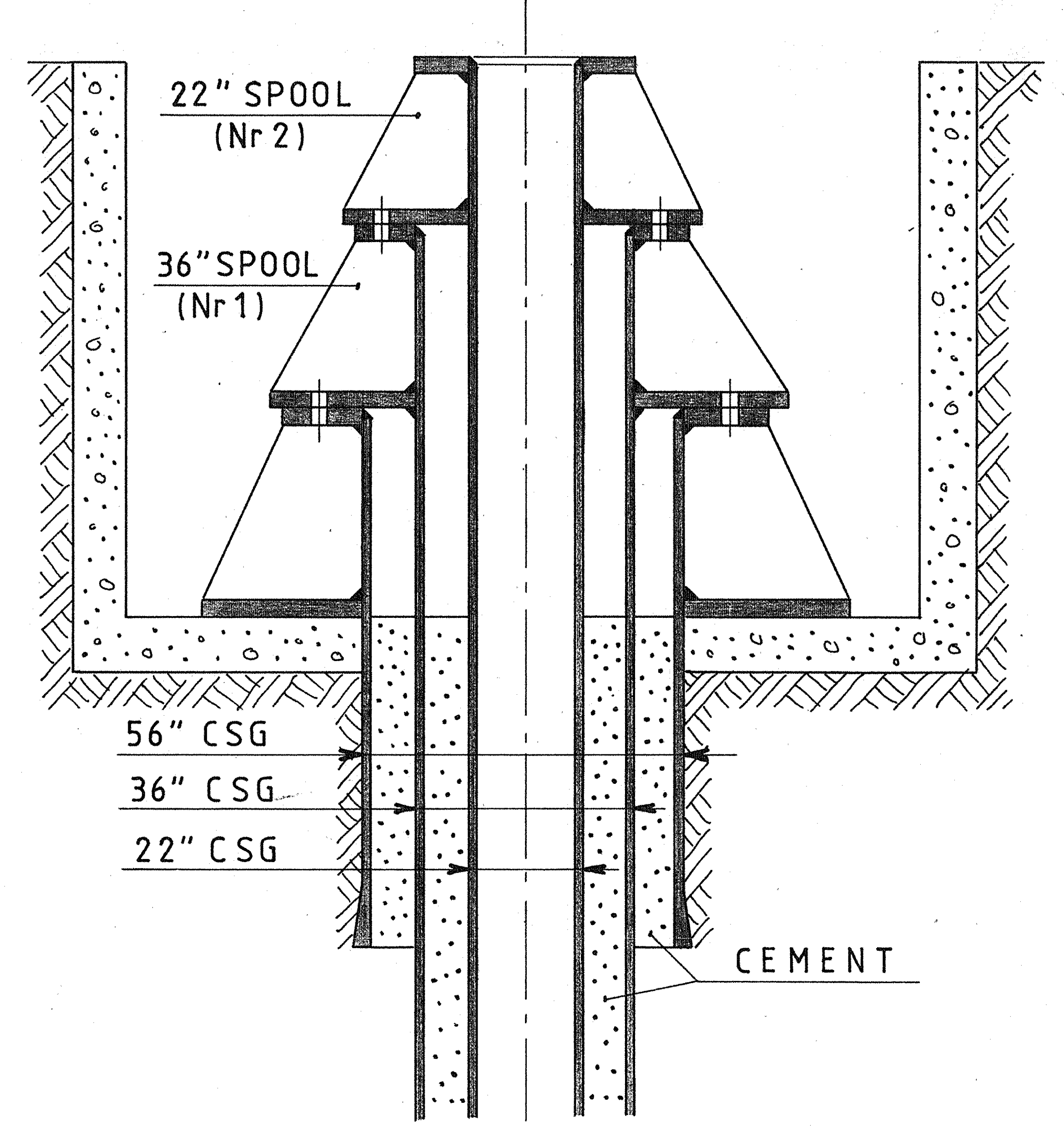
DRILLING 50 to 800m



SETTING 36"CSG WITH SPOOL Nr 1

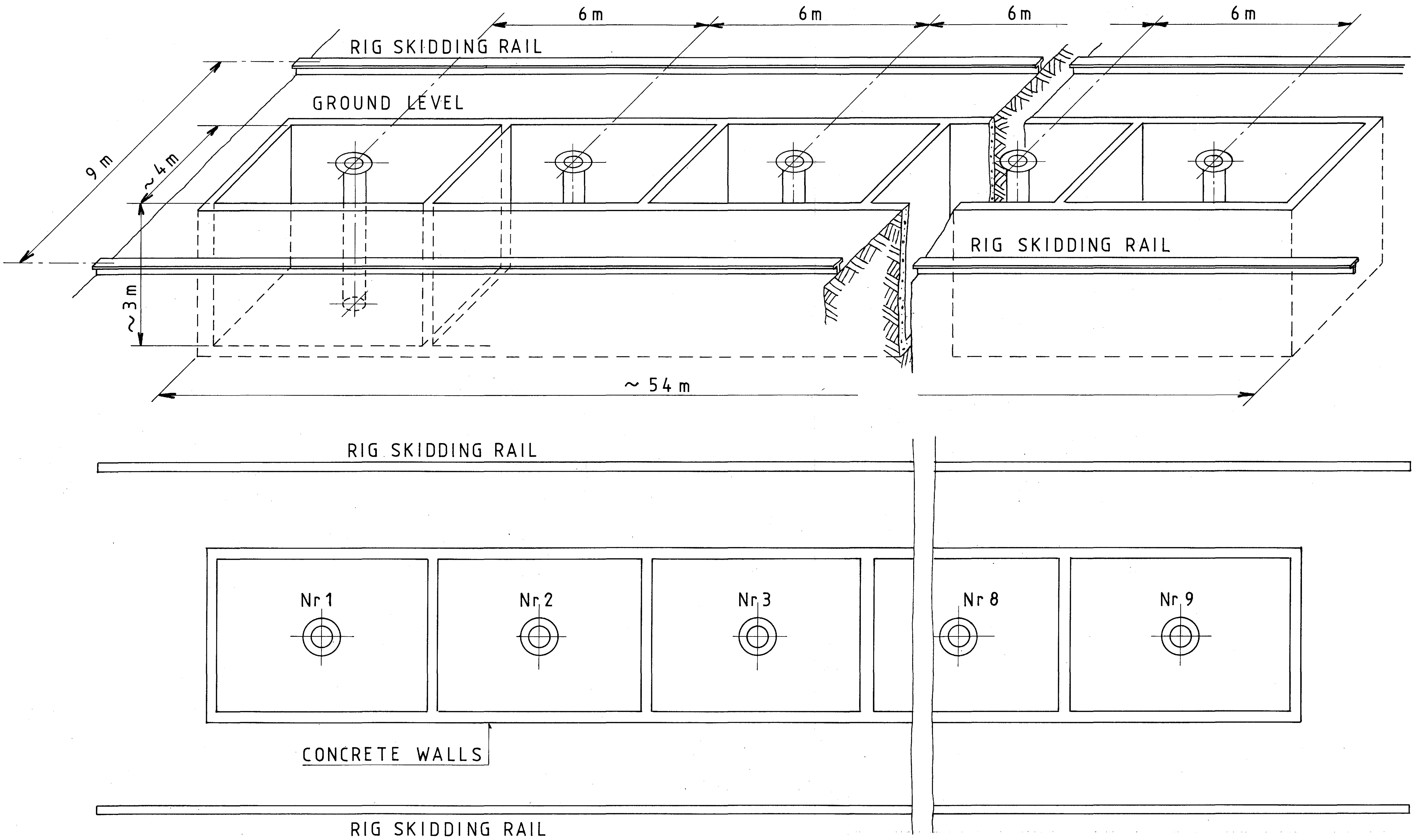


DRILLING 800 to 2000m



SETTING 22"CSG WITH SPOOL Nr 2

NAGRA	TECHNISCHER BERICHT NTB 80-04
WELL HEADS	
FOREX	DAT.: SEPT. 80 BEILAGE 13



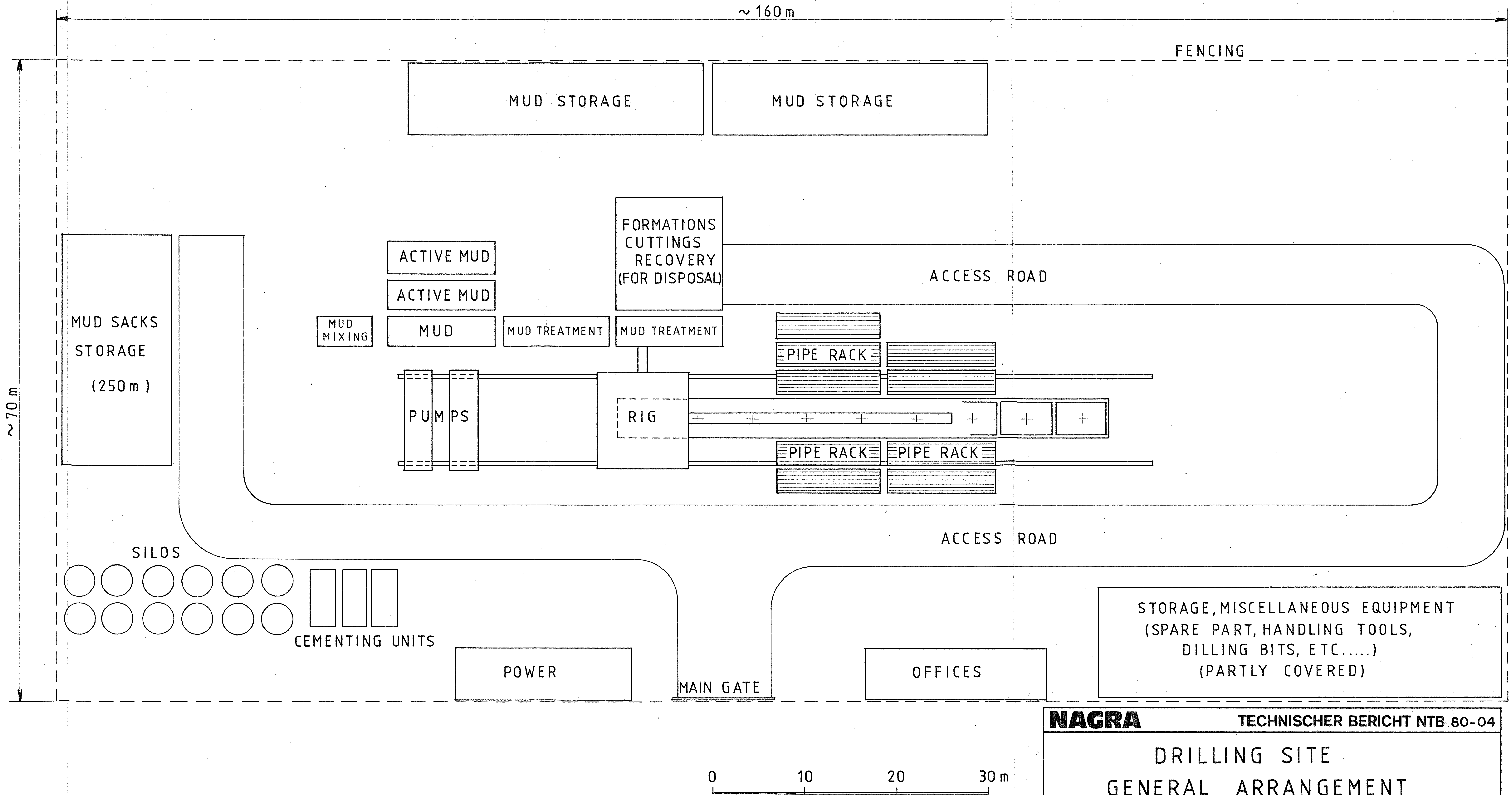
NAGRA TECHNISCHER BERICHT NTB 80-04

CELLAR ARRANGMENT

FOREX

DAT.: SEPT. 80

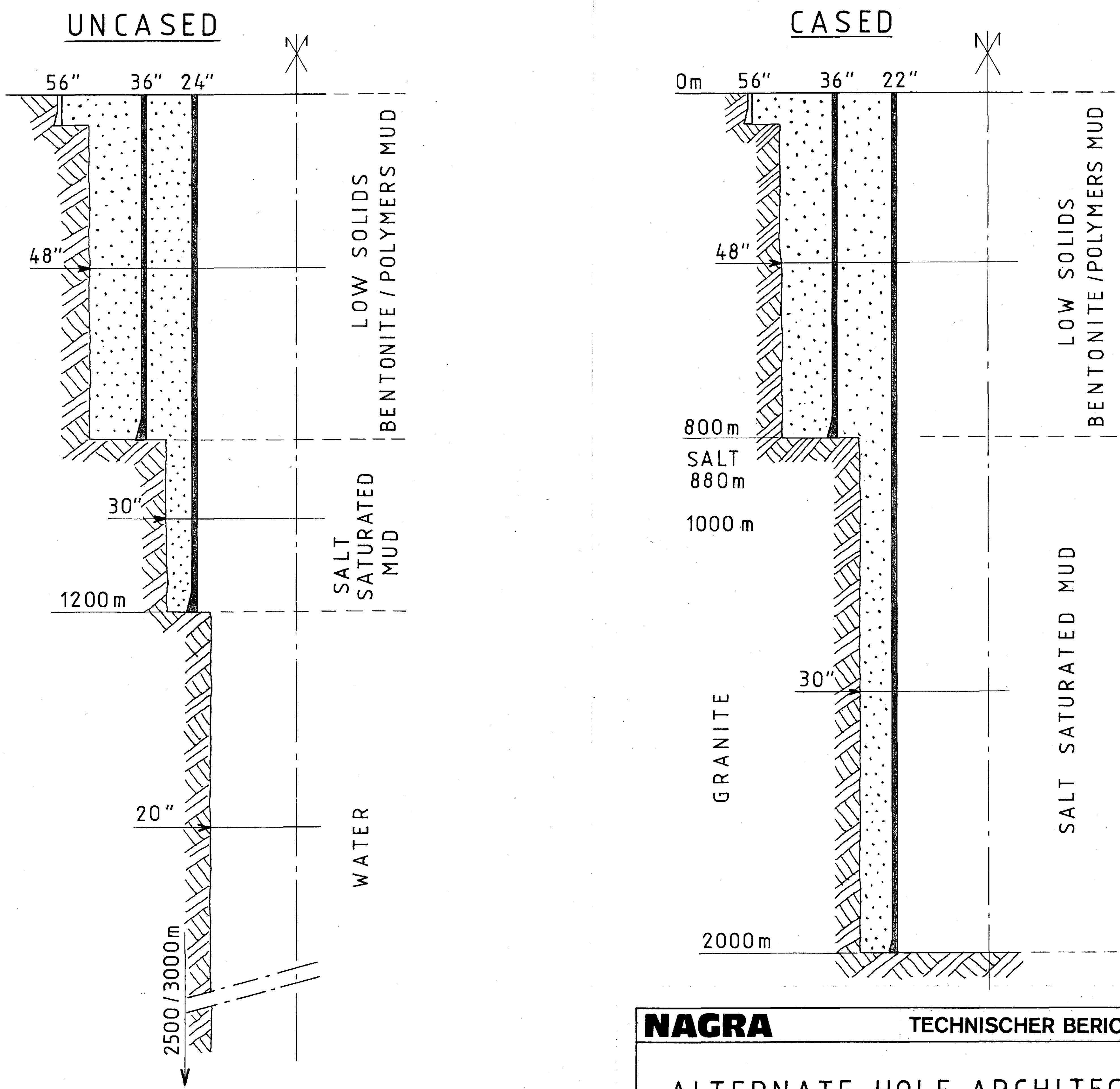
BEILAGE 14



NAGRA **TECHNISCHER BERICHT NTB 80-04**

DRILLING SITE
GENERAL ARRANGEMENT

FOREX | DAT.: SEPT. 80 | **BEILAGE 15**



NAGRA	**TECHNISCHER BERICHT NTB 80-04**

ALTERNATE HOLE ARCHITECTURE

FOREX	DAT.: SEPT. 80	**BEILAGE 16**